This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

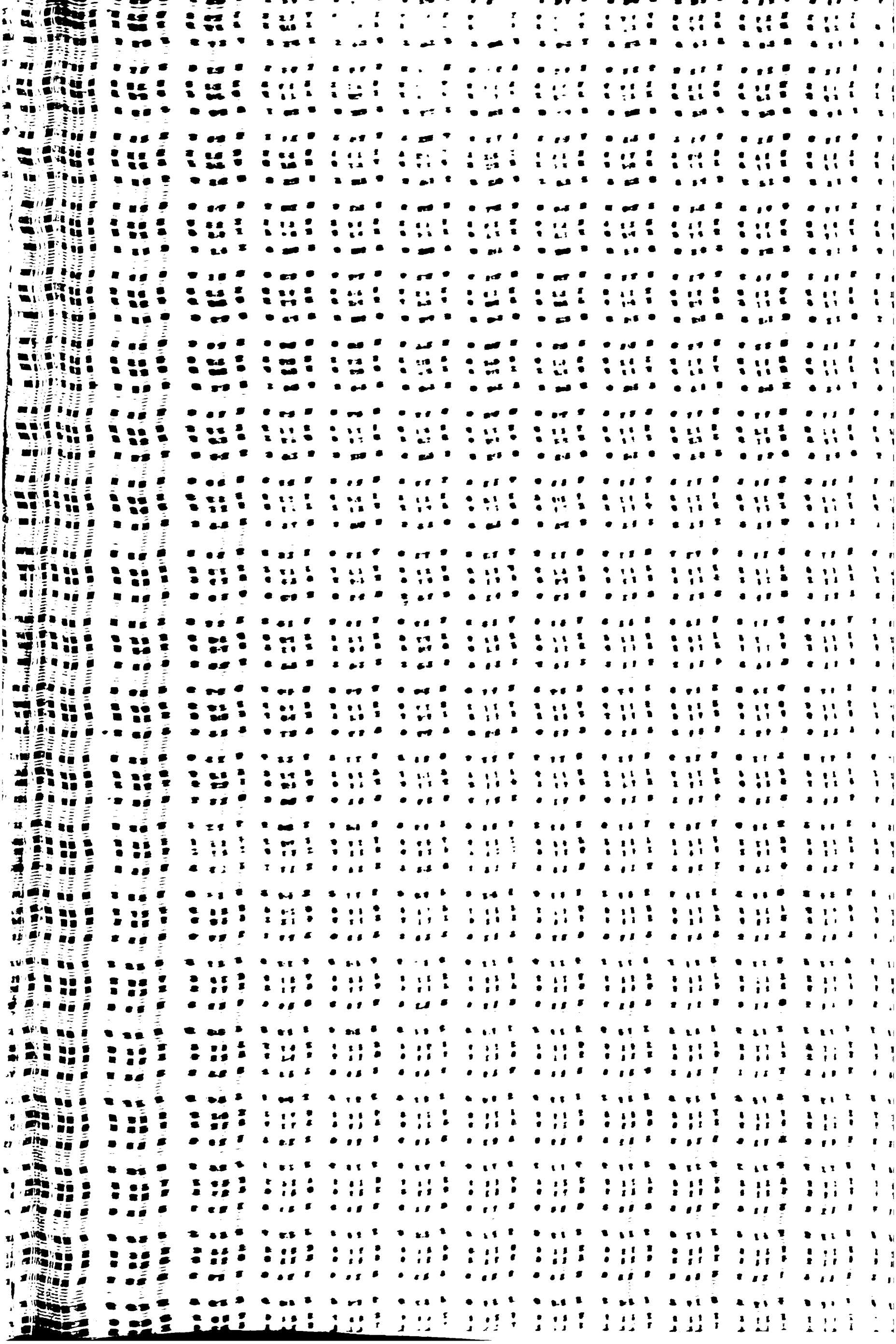
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

1817
ARTES VERITAS SCIENTIA
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
TUEBOR
CIRCUMSPICE

THE GIFT OF
Chas. L & F.W.Smerling



1817
ARTES VERITAS SCIENTIA
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
TUEBOR
SI QUÆRIS PENINSULAM AMŒNAM
CIRCUMSPICE

THE GIFT OF
Chas. L & F.W.Smerling

ELECTRICITY FOR ENGINEERS.

J. H. YEWDALE & SONS CO.,
ELECTROTYPERS, PRINTERS AND BINDERS,
MILWAUKEE, WIS.

PART I—CONSTANT CURRENT.

ELECTRICITY

FOR

ENGINEERS.

A CLEAR AND COMPREHENSIVE TREATISE ON THE PRINCIPLES CONSTRUCTION AND OPERATION OF DYNAMOS, MOTORS, LAMPS, INDICATORS AND MEASURING INSTRUMENTS; ALSO A FULL EXPLANATION OF THE ELECTRICAL TERMS USED IN THE WORK.

REVISED EDITION.

BY CHARLES DESMOND.

CHICAGO:
JOHN ROBERTS & CO.,
1894.

Engin. Library
TK
145
.D46
1894

Copyright, 1894,
By JOHN ROBERTS.

Engin.
gift
Chas. & E. Fill Smerling
7-16-74
1065018-210

CONTENTS.

CHAPTER VI.

CHAPTER VII.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

CHAPTER XIII.

CHAPTER XIV.

CHAPTER XV.

CHAPTER XVI.

CHAPTER XVII.

CHAPTER XVIII.

CHAPTER XIX.

CHAPTER XX.

CHAPTER XXI.

CHAPTER XXII.

CHAPTER XXIII.

ELECTRICITY FOR ENGINEERS.

CHAPTER I.

ELECTRICITY.

WHAT is electricity? This is a question that is frequently asked, but has not yet been satisfactorily answered. It is a force, subject to control under well known laws. Steam is also a force—that is, it is capable of doing work when rightly applied, and in connection with machines designed to use it. It does not matter, seriously, to us what electricity is, so long as we can produce it and compel it to do work. Practical results are what we are after.

We will try to explain how electricity is produced, and how it is used in some of the electrical machines that are now in use in nearly all parts of the world.

Engineers in charge of machinery, naturally want to understand the construction of the different machines and the principles of their working—the "how?" and "why?" Having this knowledge, success depends upon *watching* and *doing*, or, more simply: "Know how" and "Do it."

We know of several ways by which we can produce electricity, and we are familiar with a few ways in which we can make use of it. In these articles we will investigate electric-light machinery more particularly, endeavoring to explain the construction of the different parts, their uses, why they act so and so, how to keep them in condition to produce best results, how to renew worn-out

parts, how to repair breaks, and get an understanding of what electricians mean by some of the words and terms of which they make such frequent use.

In trying to explain these things, as I understand them, I will make comparisons, as far as possible, with things we are more familiar with as engineers—for it must be remembered that I am writing for engineers.

In the use of electricity to supply light, as in the arc and incandescent systems, different qualities are required, and in the transmission of power by the use of motors still other qualities are sometimes called for, which I will try to explain as I go along in a manner that, I think, you can understand.

The electric current is a flow of—something, along the wire. There are reasons for believing that there are two kinds of electricity—positive and negative—which are usually represented by + for positive and — for negative. These signs are found quite useful on diagrams, a number of which will be found in this book.

+ AND —

The direction in which a current flows is said to be always positive, and when work is done on the line the current is said to enter the work as positive (+), and leaves as negative (—), or on the negative side. Now, as this is always found to be the case, you will the better understand what is meant by positive (+), and negative (—) by considering them as a difference of pressure, as they differ only in that respect, although the direction in which the current flows makes, many times, a very great difference in the results obtained.

Imagine the steam in the boiler and steam-pipes as

being +, and the steam after it has passed through the engine as being —, for as it has done work and thereby lost some of its pressure it is negative to the steam of higher pressure.

As it is impossible to generate a current of negative (—) electricity of a higher pressure than the positive (+) current, it follows that + and — mean but a difference of pressure always flowing from + to —.

It is said that + electricity attracts — electricity, and that — attracts +, and + repels + and — repels —.

CONDUCTORS.

A conductor is any substance that will allow the electric current to flow freely through it. Most of the metals are good conductors, silver and copper being the best. Copper costs less than silver and is almost as good, so copper is most generally used. All of the lines (wires) carrying the electricity are called the conductors; thus you will understand that anything that allows the free passage of electricity is a conductor, and anything that prevents the passage of electricity is a non-conductor. In the use of electricity it is just as important to have good *non*-conductors as it is to have good conductors.

The earth (ground) is a good conductor, and there is where a great deal of "trouble" comes from, by the wires making contact with (touching) some substance that will conduct the current (flow of electricity) to the earth. Water is a conductor, and if the wires are wet, and their supports also, and there are any conducting substances that will allow the passage of current to the earth, then a ground is formed, and a second leak to earth will certainly produce trouble, and in some cases burn out the armature of a dynamo, and cause other troubles.

All substances will allow of the passage of some electricity, but as there are substances that offer a very strong resistance to its passage they are generally called insulators, or simply non-conductors.

Some of the best conductors are:

1. Silver,
2. Copper,
3. Gold,
4. Zinc,
5. Platinum,
6. Iron,
7. Tin,
8. Lead,
9. Mercury (quicksilver),
10. Charcoal, coke, plumbago,
11. Acids,
12. Salt water,
13. Water.

Silver is about six times as good a conductor as iron. That is, if you take a silver wire and an iron wire of the same size and length, and pass a current of electricity through them, it will pass through the silver six times as easy as it will through the iron; or, it would be necessary to use an iron wire six times as large as the silver one to carry the same current with the same loss.

Lead will conduct only about one-eleventh as well as silver. Mercury (quicksilver) has about *fifty* times the resistance of silver, and yet is often used as a conductor.

In the list of conductors given above you will notice that charcoal is classed as a conductor.

Some substances used for insulating purposes may be charred (carbonized) by heat, and then are conductors. Other explanations of this will be given further on.

NON-CONDUCTORS OR INSULATORS.

By non-conductors or insulators electricians mean any substance that will prevent the passage of the electric current. As engineers make use of a non-conducting cov-

ering for their steam pipes and boilers to prevent the radiation of heat, so electricians use non-conducting coverings for the wires carrying the current to prevent leakage or escape of the electricity. The substance generally used on the wires of dynamos, lamps, regulators, and in most places where the wire is not exposed in a way that the covering can be rubbed off, is usually cotton or silk; and then to prevent the covering from absorbing moisture from the air, or in any other way, it is coated with paraffine, paint, varnish, shellac or asphaltum. These materials are most frequently used, and answer the purpose very well, for they are good insulators and do not readily absorb moisture.

Generally speaking, the best non-conductors of heat are the best non-conductors of electricity. The "air space" being, I believe, the best non-conductor of heat, so it is the best non-conductor of electricity, providing that the air be *dry*, for *moisture*, whether it be in air or paper or asbestos or any other substance, is a conductor of electricity to a certain extent.

Some of the best insulators are:

1. Dry air,
2. Mica, sometimes called isinglass,
3. Paraffine,
4. Hard rubber,
5. Shellac,
6. India rubber,
7. Gutta percha,
8. Sulphur,
9. Glass,
10. Silk,
11. Asbestos,
12. Woolen cloth,
13. Cotton fibre or cloth,
14. Dry paper, cardboard,
15. Porcelain,
16. Dry wood,
17. Oils.

When a wire of small resistance and an insulator of high resistance are used upon a circuit the best results are

obtained, for the less the resistance of the wire the easier the current is transmitted, and the higher the resistance of the insulator the less the loss of current by leakage and the less the waste of energy in transmission.

One of the most important points in keeping up electric machines and circuits is, be sure of your insulation. This can be done by the use of good non-conductors that will not be affected by surrounding circumstances, but this is something that is very hard to determine until time has demonstrated just what those surroundings are.

In many places there are gases that will attack the insulating substances and ruin their non-conducting properties, thus allowing the current to leak away until there not being sufficient to do the work, bad results follow and the system is condemned for a fault of insulation.

In packing houses there is nearlv always trouble, because the steam, always present, has destroyed most insulations after it has acted upon them for a time. The use of bare wire in such places has not been a success usually, for the moisture has covered the supports and then dust has gathered until in many places leaks have formed to such an extent that the energy wasted was sufficient to impair the working of the whole system.

Some underground lines have been exposed to gases. coming from the earth, that have destroyed the insulation to such an extent that the whole of such circuits have been abandoned and other insulating substance tried in their places.

The subject of insulation is one that can not be too closely looked after in an electric plant, for you understand that it requires electric power to do work, and no matter in what shape that work may be, whether motors,

arc lamps or incandescent lamps, it requires horse-power or foot-pounds to do it, and any leakage means that much loss. An arc lamp, for instance, requires just so much electricity to give good results, and the loss of even a small portion of that amount causes the lamp to burn badly.

You may accept it as a fact that the *mechanical* part of the lamps and dynamos are all right, and if dynamos and lamps are kept *clean* so that they will work *free*, and there is no accumulation of oil and dirt to form a conducting substance for the passage of the current, then everything will work well *if your circuits are well insulated.*

ELECTRO-MOTIVE FORCE—VOLTS.

By electro-motive force electricians mean about the same as engineers mean by pressure. Electro-motive force is usually written e. m. f., and the unit of pressure is called the volt.* Engineers speak of so many *pounds* pressure and electricians speak of so many *volts* e. m. f. They mean about the same quality, for it is the electro-motive force that pushes the current through the wires, so it is the pounds pressure that pushes the steam through the pipes and does the work. A high e. m. f. is required where the current is to be carried a great distance, or where it passes successively through different apparatus, as in most arc lighting systems, for there it passes first through one lamp, then into and through another, and so on around the circuit till it returns to the generator. By generator is meant the machine that produces the current In passing through each lamp a certain portion of this

*The practical unit of e. m. f. or potential is called the volt, in honor of Volta, and is equal to 100,000,000 or 10^8 absolute or C. G. S. units of Potential.

e. m. f. is absorbed, just as in doing work with ... tain amount of power is lost for each port ... done, by friction, condensation, leaks, etc.

Potential is a word that is often used to ... same idea as e. m. f., but its meaning is quite ... I will try to explain.

If you are working an engine at 100 pound ... and have a back pressure of five pounds, you w... have but ninety-five pounds effective pressure. ... were using a current of 100 volts e. m. f. and ... were lost in overcoming resistance, you would ... potential of ninety-five volts. Whenever work is ... steam machinery a certain amount of pressure is ... condensation, doing work, or by overcoming frict... this loss may be considered as a loss of potenti... the use of electricity any loss in pressure (volts) ... occur from doing work or overcoming resistance i... loss of potential (effective pressure.) In an arc li... instance, the loss of potential (pressure) may be fi... volts—that is, there has been that many volts or ... energy absorbed or used up in doing the work in th... **and as *energy can not be lost*, in this case it is trans... into heat, and the greater part of that heat is utili...** the form of light.

Now you may understand that electro-motive ... (e. m. f.) means pressure, force, energy; and that pot... is understood to mean the capacity to do work, o... effective pressure.

The subject of high e. m. f. against low e. m. f. ... admit of a few words of comparison here. High e. ... like high pressure of steam is the more economical ... many ways. When used at a great distance from

...es it is usually desirable to do away with as ...friction as possible, so in the use of electricity ...able to avoid resistance except in such cases ...made useful, and they are many in electric

...ndescent lamp the little hair-like filament ...tance, and the energy required to overcome ...is transformed into heat and the filament ...hot and in that way produces the light. It ...at we depend on for the regulation of ...t dynamos, and in the arc lamp again ...element that is used to produce a steady

...resistance will be more fully explained ...some of the different dynamos, lamps

AMPERES.*

...nd what is meant by amperes we will ...flow of water and call the gallons per ... In speaking of the amount of steam ... of time we usually say a certain ...but as this is not easily understood ...given, we will try to understand the ...by comparing it with the flow of ... compressible under variations of

...twenty gallons of water per minute ... pounds; and we increase the ...pounds we will have a flow of

---

...t of current strength, and is equal to ...S. unit of strength. A current of one ...re through one Ohm.

jumping off was all right as far as he knew; but you take one of those same glass insulators and hold it near a belt that is producing a current and see if the electricity will not jump as far to that as it will to your fingers, and that current from the belt is quite weak compared with lightning.

It is the force, the tension, the e. m. f., the potential of electricity more than the quantity that usually does the mischief. But that may be easily understood by remembering that what is an insulator for low e. m. f. may be a good conductor for high tensions

RESISTANCE.—OHMS.

That principle which engineers call friction, is just what electricians mean by Resistance. In steam engineering we have no unit of friction and can only measure the amount by the force required to overcome it and speak of it as so many pounds—but in electricity we measure the resistance (friction) by Ohms.*

I think it would not do any particular good for me to try to explain to you just what an ohm is, for to get down to the fine part of it, it amounts to just about the same as when friction is understood, and electricians say that it takes a volt to force an ampere of current through an ohm of resistance.

An engineer will speak of friction by saying it takes a certain amount of pressure to overcome the friction.

Just consider that resistance and friction mean about the same thing and you will be near enough to it for all practical purposes.

---

*Ohm, the practical unit of resistance, so called in honor of Dr. Ohm. The Ohm is equal to 1,000,000,000 (10^9) absolute, or C. G. S. units of resistance. The standard Ohm is a column of mercury 1 sq. millimeter in section and 106 cm. in length at a temperature of 0° C.

In mechanics it is usually desirable to do away with as much useless friction as possible, so in the use of electricity it is also desirable to avoid resistance except in such cases as it can be made useful, and they are many in electric lighting.

In the incandescent lamp the little hair-like filament has a high resistance, and the energy required to overcome that resistance is transformed into heat and the filament becomes white hot and in that way produces the light. It is resistance that we depend on for the regulation of current, in most dynamos, and in the arc lamp again resistance is the element that is used to produce a steady light.

The utility of resistance will be more fully explained when describing some of the different dynamos, lamps and regulators.

AMPERES.*

To fully understand what is meant by amperes we will compare it with the flow of water and call the gallons per minute the amperes. In speaking of the amount of steam used in a given length of time we usually say a certain number of cubic feet; but as this is not easily understood unless other data are given, we will try to understand the meaning of amperes by comparing it with the flow of water, as water is not so compressible under variations of pressure.

If we have a flow of twenty gallons of water per minute under a pressure of fifty pounds; and we increase the pressure to one hundred pounds we will have a flow of

---

*The Ampere is the practical unit of current strength, and is equal to 1-10 or 10^{-1} of the absolute or C. G. S. unit of strength. A current of one volt potential will carry one Ampere through one Ohm.

forty gallons. So in electricity fifty volts and twenty amperes, one hundred volts and forty amperes, under similar conditions. Ampere, you understand, means quantity; but we can not put the electricity into a measure and measure it as we can water but the amperes are measured by the work they do, and like water the amperes do not grow less by doing work, but like water again the pressure or e. m. f. is what grows less in proportion to the amount of work done.

Having explained, as as well I can, without taking toc much space, the meaning of some of the more important words that are required in describing this peculiar subject of electricity, I will endeavor to make plain the principles and action of electric light machinery.

CHAPTER II.

DYNAMOS.

There are various styles of dynamos but they are all built upon similar principles. The main parts of a dynamo are shown in Fig. 1, (page 23) where *A* shows the magnet core, usually made of wrought iron, and cast into the pole pieces *B B*. Around the core, *A*, are wound the field coils, as shown at *C*.

The field coil is copper wire, generally insulated with soft cotton thread and double wound, that is, there are two layers of the thread wound on, which more effectually insulates each turn of the wire, from those nearest to it. The pole-pieces *B B* are most frequently made of cast iron, though wrought iron would be better, but owing to the cost of working the wrought iron into the required shape it has been found more economical to use cast iron and nearly as great efficiency is obtained by making the cast iron pole pieces about two-thirds larger than would be required if wrought iron had been used. The space marked *F* between the pole-pieces, where the armature is placed, is the magnetic field, so-called, because it is there that the lines of magnetic force cross from one pole to the other, as from *N* to *S*. The yoke *D* is necessary to complete the magnetic circle from *N* through the core *A*, the yoke *D* through the core of the coil *C* to *S*, and when the

armature is in its place (*F*, Fig. 1) through that to *N* again. This is practically an electro-magnet of the horseshoe form with the wire wound on near the poles.

We can make an experiment to demonstrate the principles of an electro-magnet. Let us take a piece of iron, a bolt, for instance, and wrap a number of turns of insulated wire around it leaving both ends of the wire free and leaving the ends of the bolt uncovered for half an inch or so; it doesn't matter, for our experiment, whether we leave any uncovered or leave nearly an inch without wire around it. We now connect each end of the wire to the binding posts of a two-cell battery, causing the current to pass through the wire. We now touch either end of the bolt with a piece of iron or steel and we find that they stick together, showing that the bolt has become a magnet, and will attract iron or steel. We find that when the piece of iron nearly touches the bolt, that it is drawn with considerable force toward the bolt and we find this to be the case at either end of the bolt. Now let us disconnect one end of the wire from the battery, and try the piece of iron on the bolt again. We find that it does not stick, and we conclude that it has lost its magnetism. Let us try it again, and we will hold one end of the wire in our hand so that we can touch the binding post of the battery with it, and hold the piece of iron near the bolt, about one-eighth of an inch away, and when we complete the circuit by touching the wire to the binding post we find that at the same instant the iron is drawn to the bolt. Break the circuit by taking the wire away and the iron is released. By making and breaking the circuit quite rapidly we find that the bolt is magnetized and demagnetized just as rapidly.

Connect the wire to the binding post again, now get a few nails and hang one on each end of the bolt; we find that they are held suspended and can be shaken around considerably without falling off. We touch another nail

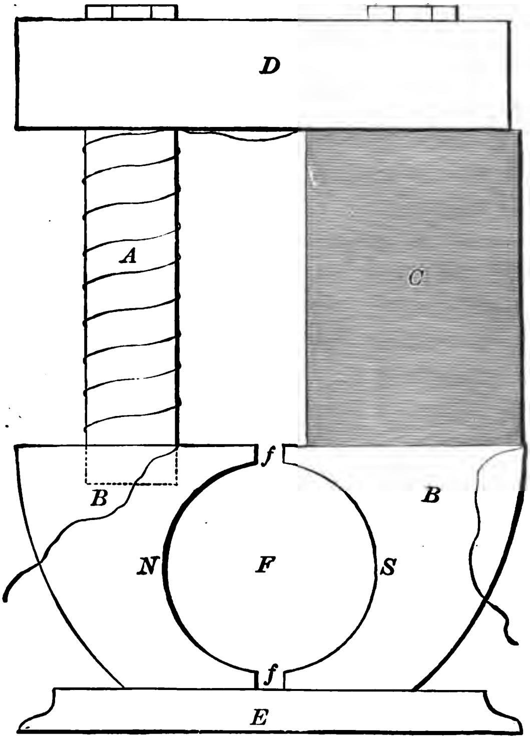


Fig. 1.

to the free end of each nail so suspended and find that it also sticks.

This shows that a large part of the magnetism is transmitted through the first nail and we will find that the second nail has also become magnetic.

If we had a greater number of turns of wire on the bolt or more battery cells connected to the wire we should find that the magnetism of the bolt would be increased, and a greater number of nails might be suspended end to end from the bolt. In winding the wire on the bolt it should be wound as close as possible, and it would not be of any benefit to wind on a greater thickness of wire than the thickness of the bolt—that is, if the bolt is one-half inch in diameter, it is of no benefit to make the whole diameter of wire and bolt more than one and one-half inches in diameter, for with this amount of medium sized wire you will get the strongest magnetism to be obtained without increasing your current by adding more cells to the battery.

Let us take our electro-magnet (the bolt wound with insulated wire) and bend it into shape like a horseshoe to bring the ends nearer together, and by now passing the current through the wire we will find that the total magnetic strength of both ends has been increased and the magnet will hold a greater weight. This is explained by reason of the poles being brought nearer together; there is less loss of the magnetic lines of force. You have noticed that whenever the current is broken the iron immediately loses all its magnetism.

This will be true only when the iron is very soft, for if the iron has been cold rolled, crystalized or otherwise hardened it will retain a portion of the magnetism, and if a piece of tempered steel—a file or cold chisel—be used in the experiment it will be found to have been permanently magnetized. That is, it has been found that if a piece of steel be once magnetized it will retain a portion of the magnetism for many days, and if a piece of *hardened* steel be used, the magnetism will remain for years.

But to keep a permanent magnet in best condition it is necessary to connect the two poles together with a piece of soft iron called the armature or keeper. This allows of a free passage of the lines of force from one pole to the other through a good conductor of magnetism thus preserving the full strength of the magnet. It is said that when the poles of a permanent magnet are connected with a soft iron armature in this way that the strength of the magnet is increased considerably in course of time.

Now if we take two permanent magnets, such as can be bought in almost any hardware store, and place their ends together, we will find that they sometimes stick together and at other times will not show any magnetic attraction.

By examining the poles of each we will find on one leg, near the end, a mark across that leg. We will find a similar mark on one leg of the other magnet. Now, if we place the marked legs so that they touch, we will find no signs of any tendency to stick—or, as we should say—they do not attract each other.

But if we place an unmarked end in contact with the marked end of the other magnet we will find that there is a strong attraction between the two, sufficient to almost, or quite, hold one magnet suspended, as the nails were held in a former experiment. By trying the ends of both magnets a few times we find that when a marked end and an unmarked are brought together they always attract; but when two marked or two unmarked ends are placed in contact, there is no attraction between them. These two poles are distinguished by the names of "north" and "south" polarity, and the differences we find in the poles of these magnets bears a close resemblance to the differences we find between *positive* and *negative* electricity. As

we have seen that there are seemingly two kinds of electricity possessing an attraction for each other and a repulsion for that of the same kind, so we will find the magnet poles not only refuse to attract like poles, but there is positively a repulsion between the poles of like nature. Let us take a horseshoe shaped magnet and a few needles and demonstrate this point. Lay a needle so that you can rub one pole of a magnet along its length, from the center to the end. You will find by touching it to another needle that it has become magnetized and attracts the other needle. By trying the other end you will find that end is also magnetized and yet it has not touched the magnet. It is impossible to produce magnetism or electricity of one polarity or kind without producing an equal amount of the opposite polarity or kind. Now with your needles, magnetize a second one the same as you did the first. One end of each will attract one end of the other, but will repulse the opposite end. To show this repulsion, fasten each needle to a small piece of cork, only large enough to float the needle and put them in a basin of water. Bring the ends of the needles close together—first one end and then the other, and note the actions of each, and after a few trials you will understand the attraction and repulsion of magnetism better, I think, than I could explain to you by writing several pages on the subject.

Magnetism plays a very important part in electric lighting, and the better we understand its properties the easier we find it to understand many of the actions of dynamos, arc lamps, some regulators and some meters.

While we find there are many substances that will practically insulate electricity, an insulator for magnetism has not yet been discovered.

A few experiments with a magnet and a compass will be of interest and greatly assist in a better understanding of many points about electric light machinery. A small compass, such as will cost anywhere from twenty-five cents up, will be useful. The compass is a round brass box, usually with a pin point projecting through the bottom to the inside. Suspended on this point is a thin piece of steel which has a small brass cup at its center. This cup is hollowed from its under side and is placed over the end of the pin. This balances the little steel bar, and as the steel has been magnetized one end of the bar will point north and the other end south. There is always some mark by which the north end of the bar may be easily determined, but when you are using a compass around electric light machines, don't place too much dependence on the mark for the polarity is liable to become changed if carried too near a dynamo, unless the needle is free to swing on its center and this is only possible when the box is held nearly level. With your magnet and the compass you can demonstrate many of the laws of magnetic polarity.

Place the compass in a level position. Bring the poles of the magnet near it. One end of the compass needle is attracted toward the magnet. Turn the magnet just far enough to bring the other leg nearest to the compass. How suddenly the needle changes ends. This is because the needle having been magnetized is polarized; that is, in this connection, one end will point toward the north *pole* of the earth, and the other end will point toward the south pole of the earth.

The effect of magnetism on steel, and why there are always two poles and why they attract each other, and several other points about the subject are not fully understood at the present time.

Now lay your magnet alongside of the compass, and you see that one end of the needle points straight toward the magnet. Turn the magnet over and the other end of the needle swings around. Move the magnet far enough from the compass so that the needle will swing only half way to the magnet. Be sure to have the magnet at the side of the needle as it stands when the magnet is not near enough to influence it. Now as the needle swings about half way to the magnet, anything that you may bring between the compass and the magnet that will stop any of the magnetic lines of force, will cause the needle to drop back. Glass is a good electric insulator; place a piece of that between them—the needle maintains its position. Try wood, pasteboard, copper, brass, zinc, anything you can find, and the result is the same—there is no deflection of the needle. You try a piece of tin or sheet iron—sheet tin is iron tinned over—and there you find something that appears to stop some of the magnetic lines. Try the tin or sheet iron in all positions, and you will be astonished, for sometimes the tin or iron appears to intercept some of the lines of magnetism, and at other times it appears to increase the number of lines. Lay the sheet down, and try the compass around it. You will find that it is polarized and you will probably notice that the opposite sides or ends of the sheet have the same polarity, and that the other sides have the other polarity.

Then try your compass on other pieces of iron around the place. Iron columns, braces, engines, shafting, fireing tools, oil tanks, kerosene cans, stoves, stove pipes, everything that is made of iron, or sheets of tin, and that remain in one position for a great length of time, are all polarized to a greater or less extent. Try the compass around the

dynamos and lamps to find the different polarities and the information you will get will be interesting and profitable, and will greatly assist you in locating troubles when they occur and give you a better understanding of the machines than you could get by waiting for some one to tell you about it.

Electricity, we have seen, will produce magnetism in iron or steel. So will magnetism produce electricity. In the dynamo we have electro-magnets producing magnetism excited by a current of electricity passing through the insulated wire around the core of the magnets, and this current is produced by the magnetism of the magnets. In our experiment with the bolt we found that the magnetic effect was gone just as soon as we broke the circuit, but if we had tested it in a way by which we could have detected a very small amount of magnetism, we should have found that there was some magnetism still in the iron, for when a piece of iron has once been magnetized a small amount of the magnetism will always remain.

Iron and steel are the only metals that have magnetic qualities to any great extent. Nickle has similar properties, but not to such a degree.

There are several other metals that possess magnetic properties to a very slight extent.

CHAPTER III.

ARMATURES.

Fig. 2 shows one type of armature for a dynamo. There are many different styles of armatures but all possess the same qualities in common. The style of armature shown in the cut can be best understood by taking it to pieces and we will suppose that we are going to do so.

Fig. 2.

We will place it in a position where we can get at it handily and turn it around on its bearings. A close examination of it, as it lies, shows a shaft, and we presume that the shaft runs clear through from end to end, for we find that both ends are of the same size and of the same kind of metal.

Next we find, at the left, an iron collar fitting quite closely to the ends of some copper strips which appear to be separated from each other by a substance of a different nature.

We will take this collar off. It is screwed on. (Some are fastened by screws.) A spanner wrench loosens it, and it comes off the hub quite easily. We find it threaded with a portion of its length inside tapered on an angle of about 60° and as we find the ends of the copper strips tapered to the same angle, but on the outsides, we conclude that the collar was intended to hold the strips down to their place, as well as against a shoulder that we may expect to find at the other end of the strips. We find a ring of a leathery appearance on the ends of the strips where the collar came off. On examination we find this ring to be about one-fourth of an inch thick, and the material we will probably find is vulcanized fibre.

Vulcanized fibre is made of paper, similar to pasteboard; some substances mixed with it allow it to be vulcanized which makes it tough like leather and hard like gutta-percha and as it does not readily absorb moisture and having a very high electrical resistance, makes it an excellent insulator. The most serious defect it has as an insulator is, that when it is heated very hot it becomes brittle and loses its insulating qualities. Mica is often used as an insulation in this place.

We will screw the collar loosely back in its place again until we investigate further. At the other end of these copper strips beyond the bend and where the end of the strips come near the outside of the armature, we find screws holding a copper wire to the strips. Remove one of these screws and we find that the wire becomes separated from the strips as it was merely laid on and held by the screw. On some armatures the wires are soldered to the strips. We will remove all of the screws that hold wires to the strips and we can then take all that portion,

from the wire to the nut, off the shaft. To remove this portion, which is called the *commutator*, we will require two bolts about nine inches long and of a size that fits into two little holes in the hub, near the shaft. We will need a piece of flat bar iron with three holes in for a yoke to put over the end of the shaft with a set screw through the centre hole. The bolts are put through the other holes in the yoke and screwed into the hub. Now, by screwing on the set screw, we start the commutator off the shaft.

Investigation shows us a collar at the other end, but as we see no way of unscrewing it, we conclude that it is solid there. We will remove the nut again, and by trying one of the strips, or *segments*, as they are called, we find that it can be easily removed. The shape of these segments is shown, side and end view, in Fig. 3. Between the segments we find vulcanized fibre or mica insulation. Good

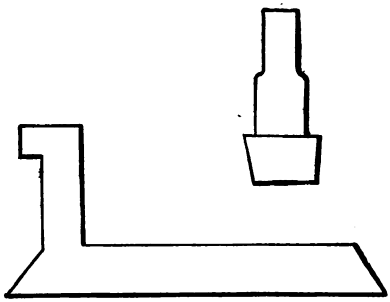


Fig. 3.

insulation is quite as important here as in any other part of the machine, although the difference of potential between adjacent segments is not generally very great. Separating the copper segments from the iron sleeve is

more insulation, and at the end where the collar is cut under to fit the ends of the segments, is still more insulation; so we find that each segment is entirely insulated from everything. In replacing the segments and getting the commutator together in shape again, we may perhaps find some difficulty in getting the segments to lie as smoothly as before we removed them, but that is easily remedied by placing the commutator in a lathe and taking a fine cut off the surface.

Now that we have examined the commutator and have an understanding of its construction, we will examine the other parts of the armature. We see that it resembles a pulley with insulated wire wound across the face and through between the spokes on the inside, forming a complete covering to the rim. As we find a number of ends of the wires at equal distances apart, at the commutator end, we infer that the wire is wound on in sections. Where we separated the wires from the segments, we find there are two ends of wire that are connected to the same screw. In some armatures of this kind there is a brass or copper clip that holds the ends of the two wires, and this clip is fastened to the strip.

Around the armature we find bands of wire wound on and soldered together solidly, but insulated from the wires that run lengthwise and that connect with the segments of the commutator. These bands serve the purpose of holding the wires in their places, preventing them from bulging outward. We will cut these bands off. We find that they are brass wire, and after a moment's thought we understand that iron wire would not answer so well in this place, for it would form a conductor for the magnetism, carrying some lines of force from pole to pole without their

passing *through* the armature, and that would be detrimental to the action of the machine, for it is necessary that the armature wires *cut* the lines of force, that is, the lines of magnetism should pass directly through the armature, from pole to pole of magnets. Then when the armature is turning, the wires cut through the magnetic lines as a saw would cut through a board across the grain. As we remove the wire from this armature we find that the wire is covered with two or three layers of cotton fibre or thread, and this is varnished on the outside. This cotton is for the purpose of insulating the wires from each other and from the iron rim. We remove several turns of wire and find another layer of wire underneath. After removing these we find that the iron rim is covered with cloth and the cloth has been varnished with shellac. The rim we will find is built of iron bars, riveted to the outside and inside of several iron rings, making an openwork iron frame armature. This cloth was wound on the rim to assist in insulating the wires from the iron, for in winding the wires tightly on the iron the wires would be very liable to cut through their covering, and, making contact with iron, would produce a ground. The *first* ground on any wire carrying an electric current is to be *avoided by all means*, for if you prevent the first one forming you will not have a second one to make you trouble. And the second ground *always does make trouble.* In removing the wire we find that the inside end of it is brought out and connected to the same clip as the outside end of the next wire. We also notice that the wire we have removed filled a section of the circumference of the armature. We infer from the number of ends of wire projecting that the wire is laid on in sections, and by counting around we find a number of

sections equal to the number of segments in the commutator.

Other armatures are built up of iron washers separated from each other by paper or other insulating substances. This separation is made for the purpose of breaking up currents of electricity that have been found to form in armatures of solid metal, and these currents heat an armature very hot because they have no way to escape, but their force is expended in heating the metal. The armatures and poles of some dynamos become very hot from this cause. The currents are called Foucault currents. A Frenchman by the name of Foucault first explained the cause of heating of armatures and magnets, by showing that currents of electricity were produced within the mass of the metal when it was rapidly magnetized and demagnetized, or when it is subject to sudden and continuous changes of polarity, and these being short-circuited within the metal, produced the heat. Foucault suggested a way of overcoming this by dividing the metal in the direction of its travel in the case of armatures and in the pole-pieces by slotting them in the direction of travel of the armature.

The more thoroughly this principle is carried out in construction, the less heating there will be from that cause. One builder of dynamos has very nearly doubled the capacity of his machines by simply making his armature of hoop iron rolled into a ring with each turn insulated from the others.

CHAPTER IV.

THE CURRENT—DIFFERENT STYLES OF DYNAMOS.

In dynamo-electric machinery the current is the result of the following law, discovered by Faraday in the year 1830:

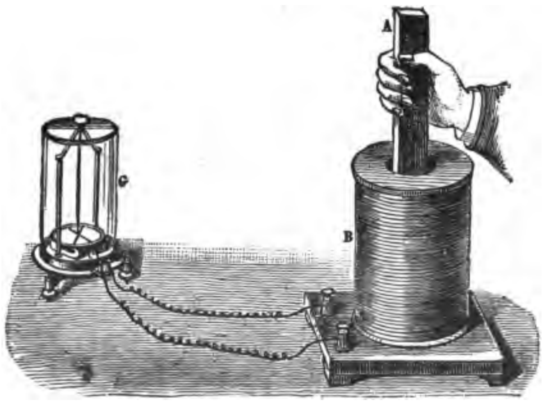


Fig. 4.

A current of electricity is induced in a closed conductor by the approach or withdrawal of a magnet, or any change in the intensity of magnetism in a neighboring magnet.

Figure 4 will illustrate the idea. *A*, is a bar magnet *B*, is a coil of wire. *G*, is a galvanometer. The coil is

the conductor which is closed by being connected with the galvanometer. The galvanometer is an instrument to show when a current is passing.

With this arrangement, a current of electricity will be produced when the magnet is suddenly pushed into the hollow of the spool and will be shown by the swing of the needle of the galvanometer. Withdraw the magnet and the swing of the needle will show that a current flows when the magnet is withdrawn also, but you will notice that the needle swings in the opposite direction. This fact proves that a current flowing in one direction is produced when the magnet is pushed into the coil, and a current in the opposite direction is produced when the magnet is withdrawn. Another illustration can be made by moving the magnet back and forth in the coil so that it is at no time wholly withdrawn. This will prove that a current can be produced by changes in the magnetic intensity, for a magnet is not of the same strength throughout its length, but varies from one polarity at one end to the opposite polarity at the other end, giving different degrees of strength from the ends to near the centre where the opposite polarities neutralize each other and no magnetism is found outside the iron.

By regulating the movement of the magnet to the swing of the needle sufficient current can be produced so that it will cause the needle to swing to quite an angle. The greater the number of turns of wire on the spool the more intense will be the current produced.

In this experiment, it does not matter particularly whether the magnet be introduced into the center of the coil or passed along the side, a current will be produced in either case; or if the wire is passed across the end of the magnet the result is the same.

The last conditions more nearly represent the production of current in a dynamo as shown in Fig. 5 where, *N*, *S* are the magnet poles and *a*, *a* the wires on armature and the arrow shows the direction in which the armature turns. Here you will notice that each section of wire passes through a magnetic field of different degrees of intensity and produces a current of corresponding strength at each portion of its travel. It will be noticed that the brushes are in position to collect the current just as the section is leaving the field. This is the position where we find the greatest difference of magnetic potential—between the pole piece and the neutral line, *n*, and from there we also get the current of greatest intensity. Now this point of greatest intensity changes slightly according to the degree of magnetization of the field magnets and also according to what is called the magnetic lag of the armature. The magnetic lag is the resistance offered to the sudden change of polarity in the iron of the armature, and compels a slight change in the position of the brushes with every change of load on the dynamo.

Some dynamos are so contructed that the position of the brushes need not be changed for any variation of load. In armatures of the kind already mentioned, the winding is practically a continuous wire wound around the armature with loops, at equal intervals, brought down to the commutator segments, as shown in the accompanying cut at *C*, and explained under Fig. 2. This closed circuit winding, as it is called, brings all the sections of wire in circuit with the brushes at all times, and as all wires that are cutting lines of force are producing some current, it is reasonable to suppose that there is a gain in winding an armature on the closed circuit plan. The armature wire

passing through the magnetic field produces a current which flows to the commutator segments and is there collected by the brushes and from there it goes to the line to do the work.

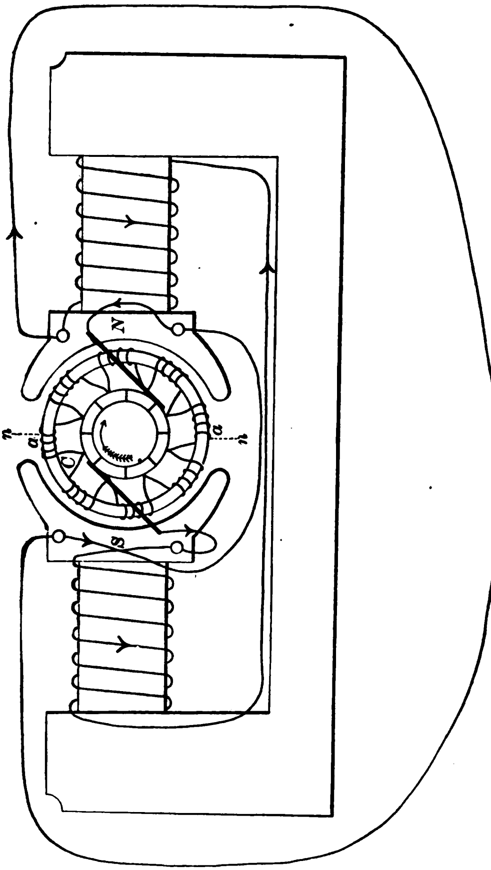


Fig. 5.—Series Wound Dynamo.

EXCITING THE MAGNETS.

The magnets of most dynamos are excited by the current produced by the machine itself, which can be done in two ways. By putting the magnets in shunt or in series with the main line.

You will remember that when a piece of iron has been once magnetized it will always retain a small amount of magnetism. Now the pole pieces being slightly magnetic, we find, on starting the dynamo and placing the brushes in position on the commutator, that there will be a feeble current flowing in the circuit. If the ends of the field-coils be placed in contact with the brushes, as shown in Fig. 6, a portion of the current will pass through the field-coils and produce stronger magnetism in the fields and a stronger current will be the result.

The current in the circuit and the magnetism of the fields will both continue to increase until the resistance of the field circuit will allow of no greater portion of the current to flow in that direction.

SHUNT WOUND DYNAMOS.

Dynamos excited in this way are called "shunt wound," or shunt dynamos. If the current was taken from one brush and led through the field-coils, then to the line or outer circuit and back to the other brush (Fig. 5), it would produce the same results but would then be a "series" dynamo, for the magnets would be "in series" with the lamps or other work.

In a shunt wound dynamo, Fig. 6, only a small portion of the current passes through the fields. The magnets are wound with small wire and as a consequence of its being small it has high resistance.

High resistance in the field-coils of a shunt dynamo is a necessity, for if the resistance of the field circuit was low the greater part of the current produced would pass through the fields and that would cause trouble in more ways than one. The resistance of the shunt winding is

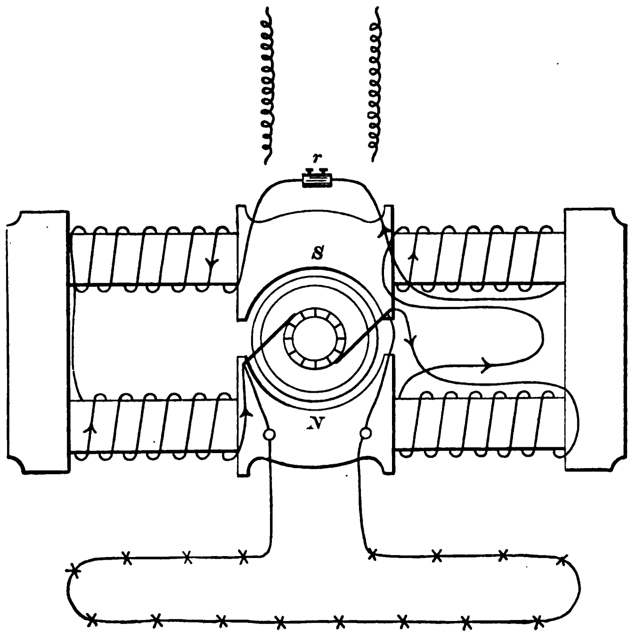


Fig. 6.—Shunt Wound Dynamo.

so proportioned that only a small portion of the current passes through the fields; but as there are a great many turns of wire, each turn adding a certain amount of energy to the magnets produces, by the great number of turns what is lacking in the small amount of current passing through the field coils.

A little study on this subject will show that a shunt dynamo is a very good arrangement; for when the resistance of the external circuit is high—that is, when there are a great number of lamps "in series" burning—then there will be more current forced through the fields, more magnetism in the magnets, more electro-motive force generated, more work done, and more power required. When some of the lamps are switched out the resistance of the lamp circuit falls and less current passes through the fields, and consequently the magnetism is lessened and as a result the electro-motive force falls; so you see that if the wire in the fields was of exactly the required number of turns and had just the correct resistance, the dynamo would be self-regulating if there were no other causes for disturbance, but as there are several disturbing causes, it is impossible to make an ordinary shunt wound dynamo self-regulating.

These dynamos are regulated in a very simple manner which will be explained under the head of "Regulation" where the various methods of dynamo regulation will be clearly explained and fully illustrated by cuts.

SERIES WOUND DYNAMOS.

In a series wound dynamo, Fig. 5, you will notice by tracing the wire, that all of the current passes through the field-coils and the wire is larger than in a shunt dynamo for it has a greater amount of current to carry, and as the current develops considerable heat the wire must necessarily be large enough to carry the current without developing more heat than the insulation can stand before losing its insulating qualities.

The heating properties of currents and the carrying capacity of wires will be spoken of in their proper places.

CONSTANT CURRENT AND CONSTANT POTENTIAL DYNAMOS.

The distinguishing feature between constant current and constant potential dynamos is, that in the constant current dynamo the regulation is arranged in such a manner that the current or amperes never rise above or fall below a given number, while the e. m. f. is regulated according to the changes in the resistance of the circuit. Constant potential dynamos are so regulated that the potential, or e. m. f. remains the same, as, for example, at 100 volts while the amperes vary to meet the requirements of the work. Constant current is used almost exclusively in series lighting, with both arc and incandescent lamps.

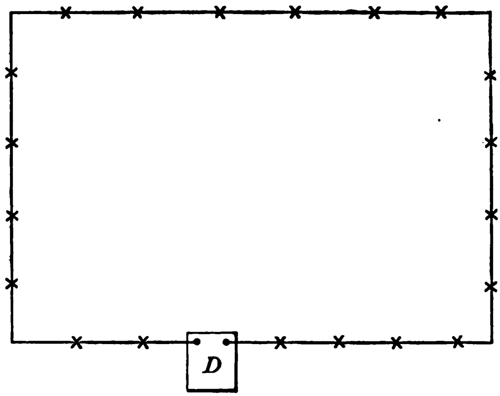


Fig. 7.—Series System.
D—Dynamo. ×—Lamps.

Where incandescent lamps are placed in series a constant current is necessary, for it requires the same amperes of current to produce light in one lamp as in a dozen, and the same current passes successively through each lamp. To explain this more fully, we will take an arc light plant

of twenty lamps in series, Fig. 7. Arc lamps of the different makes require from six and one-half to twenty-three amperes of current to produce the required candle power. For this explanation we will consider that we have lamps requiring ten amperes and fifty volts, so twenty of these lamps would require twenty times fifty, or one thousand volts, for here, you will understand, the resistance of the lamp, when burning at its full candle power, is five ohms, and to drive ten amperes through five ohms requires ten (amperes) times five (ohms) which is fifty volts, for, as you will remember, it was explained before that it required volts of e. m. f. to force the amperes (current) through the ohms (resistance). Now each lamp consuming fifty volts (pressure) in doing the work, there is, of course, a "loss of potential" of that amount—fifty volts, at each lamp. Now if one-half, or ten of these lamps be cut out, one-half of the resistance is removed and, of course, only one-half of the e. m. f. will be required to force the same amount of current (ten amperes) through the remaining lamps.

In the constant potential systems the lamps are placed in multiple arc, as it is called, the lamps being connected between the mains, as shown in Fig. 8. Here constant pressure or potential is required on the mains, and the current changes according to the number of lamps.

The different makes of incandescent lamps are of different resistances, requiring different potential and different amount of current.

Generally speaking, we can say that the greater the resistance of the lamp the less current required but a greater potential is necessary. We will take a lamp requiring 75 volts and one ampere to produce the required candle power, and by referring to the diagram, Fig. 8, you will notice that

as long as the potential is kept the same between the two mains, that an equal amount of current will pass through each lamp, if lamps of the same resistance are used. Taking 100 lamps in circuit, the requirement will be 75 volts and 100 amperes. Cut out 20 lamps and there would

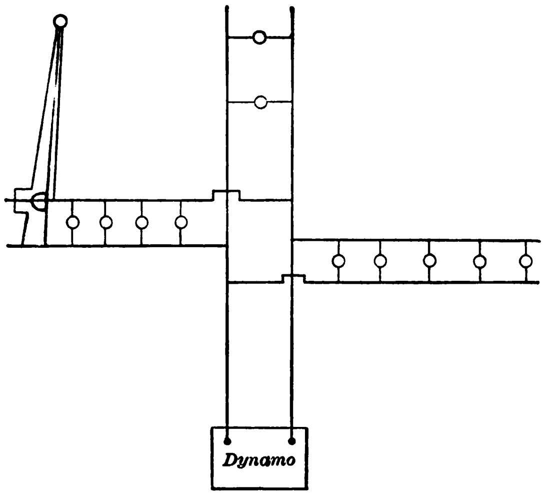


Fig. 8.—Parallel or Multiple Arc System.

be a surplus of current that would give one and a quarter amperes to each lamp remaining, if the regulator did not reduce the current to the required amount. This regulation is produced in several different ways in the different systems and a clear explanation of each will be given when we come to the subject of regulation.

CHAPTER V.

INCANDESCENT LAMPS.

The incandescent lamp as shown in Fig. 9, will fairly represent the principles of the different makes of incandescent lamp now in extensive use in this country. The lamp consists essentially of the glass bulb *a*, the carbon filament *b*, and the conducting wires *c*. The glass bulb is blown on the end of a glass rod, as shown by dotted lines

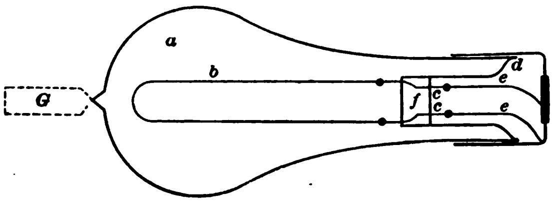


Fig. 9.

at *G*. The filament is made of linen, cotton or silk thread, paper, cardboard, bamboo-fibre and several other substances, by different manufacturers. The filament is first made into the desired shape and size—the horseshoe shape, as it is called, being generally preferred, though it is sometimes given a half spiral twist, or a round turn at the top, or a wavy or corrugated form, but generally the plain horseshoe form is preferred as it gives as good results as any. After the filaments are made to size and shape, they

are carbonized by being submitted to a high heat in a furnace and *out of contact with air*. That is they are packed in an iron box and covered with a substance that will not burn and that will keep the air from coming in contact with the filaments; sand, pulverized fire clay and other substances are used. The object is to keep out the air, for if the air got to the filaments while highly heated they would be consumed instead of carbonizing. When the box is full the cover is tightly fastened on and the cracks luted with fire-clay. The boxes are then put into an oven and kept at a high heat—generally a white heat for a number of hours or until they are thoroughly carbonized. In preparing the substance from which the filaments are formed, it is treated by chemicals to break down the structure before it is carbonized. This is considered necessary, by some.

Before carbonization the filaments are trimmed down to gauge. The less the sectional area the greater the resistance will be for the same length, and consequently the smaller the amount of current required to heat the filament to the necessary degree of incandescence to bring it to the required candle power.

Platinum wire has been used as a filament for lamps, but its cost was considerable and carbon has been found to give fully as good, if not better results, so its use has, practically, been discontinued for the present.

It has been considered desirable to make the resistance of the filaments very high, but as this is accomplished by reducing the sectional area a limit was soon reached below which it was impracticable to go on account of the filaments being too easily broken. After the filaments have

been prepared as described above they are connected to the platinum wires marked *c*.

These platinum wires are passed through a glass tube flared at one end and the opposite end of the tube sealed around them by softening the glass and with a pair of pliers squeezing it tightly together, as at *f*. Platinum wire is used in this place in preference to any other material because its expansion and contraction is more nearly the same as glass than any other metal. If the expansion and contraction of these wires was much different from that of the glass, an opening would be made through which air would soon work into the globe and that would put an end to that lamp, for the carbon filament would immediately burn off.

This joint between the carbon and the wires *c*, is made in different ways by different manufacturers.

In some lamps the filaments have been made with flattened ends and fastened between clamps, formed by the end of the wires and held by a screw.

Another way is to copperplate the ends of the filament and solder to the wires. In another lamp the carbon is fastened to the wires by a cement especially devised for this purpose. Just below where the wires pass through the glass a copper wire *e* is usually soldered on to the short platinum wires. This is done as a matter of economy. After the filaments are connected to the conducting wires they are in most cases placed in a hydro-carbon liquid and a current of electricity passed through them that raises the filaments to incandescence by which the resistance of the filament is equalized throughout its length by carbon, from the vapor, being deposited on those parts of the filament that become the more highly heated. This pro-

cess is technically called "flashing." The filament is next placed inside the bulb and the ends of the tube and bulb fused together, as shown at *d.* A cap is placed over the end, and fastened, with plaster of paris, usually. Various ways of connecting the wires to these caps so they may be readily connected to the lamp sockets are resorted to and each manufacturer seems to have a different way, which are all more or less convenient and reliable in practice.

The lamp is now ready to be "exhausted." The tube from which the bulb was blown (shown by dotted lines *G*,) is now connected to the "vacuum pump" and the air exhausted until the desired degree of exhaustion is produced. This is determined by frictional or static electricity.

You can test any of your lamps to show the degree of vacuum by holding the lamp near a belt that gives off electricity. If a plume of purple or bluish colored light shows inside the bulb, that bulb is not well exhausted, it contains air and the lamp will be short lived. But if dazzling white sparks show themselves on the glass and a snapping sound is heard at the same time, you may be satisfied that that lamp contains a very good vacuum. The causes of short life in an incandescent lamp are usually considered to be poor vacuum, poor quality of filament, though this last does not usually occur in any of the lamps of the well known systems. The jar in handling sometimes causes a slight fracture in the carbon filament that will necessarily result in its burning off at that spot in a very short time.

Running the lamps above their rated candle-power will shorten the life most materially if continued even for a very short time. Allowing the candle-power to fluctuate

is also spoken of as a cause for their burning out. It is, at least, very bad practice and shows a lack of care or interest in the plant.

If you keep your circuits free from grounds—and *this is an exceedingly essential point in any system of electric lighting*—and keep your brushes and commutators in good order you will not be troubled very much by lamps burning out before their guaranteed time.

The author has had charge of plants of different systems where lamps by the dozens could be shown that had burned more than twelve hundred hours and a few that had given as high as sixteen hundred hours' service. A large part of this result is attributed to the strict observance of the points mentioned above.

Incandescent lamps are run on at least four different systems.

IN SERIES.

Lamps used in series with arc lamps are usually of low resistance, generally four and one-half or five ohms and requiring nine to ten amperes of current. This kind of lamp is designed to take the place of an arc lamp and may be placed in any part of the circuit. The carbon in lamps of this kind is shorter and much thicker than in lamps used in multiple arc. The carbon being shorter and thicker reduces the resistance in two ways, for, as you will remember, it was mentioned in a former portion of these articles that the resistance varied as the length of conductor. Consequently the shorter the conductor the less the resistance. And in another way—the greater the cross sectional area the less the resistance for it is the mass of the material that conducts and not the surface, as many

suppose. The carbon being thicker requires more amperes of current to heat it to the required degree of incandescence.

Incandescent lamps used in series require an automatic cut-out that will instantly close the circuit whenever the lamp burns out; otherwise an arc would be formed between the ends of the broken carbon which would soon be

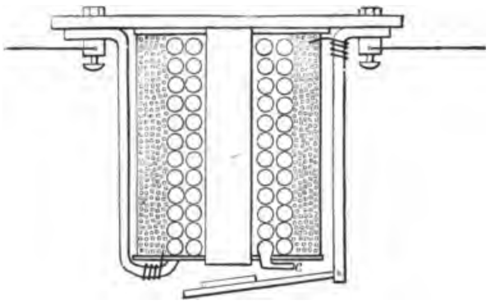


Fig. 10.—Automatic Cut-Off.

consumed, the glass melted and consequences more or less serious, according to the surroundings, would follow. The cut-outs used for this purpose vary considerable in style but their principles are the same. The one illustrated in Fig. 10, will give a general idea of them all.

This consists of an electro-magnet wound with fine wire and connected around the lamp. This wire has a resistance so high that only about one per cent. of the current passes through it while the lamp is in action; but should the lamp burn out, enough current is forced through the fine wire to increase the magnetism of the core sufficient to attract the armature and close the circuit through the larger wire at *e*. This larger wire is also

wound around the core with a few turns which serves to keep the core magnetized and that keeps the armature in place, allowing the current a free passage around the lamp until a new lamp is put in. A diagram of the series system is given in Fig. 7.

MULTIPLE ARC.

A diagram of the multiple arc system is shown in Fig. 8. In this system any lamp can be turned on or off at will by simply turning the turn-off, in the lamp-holder, which makes or breaks the circuit through that one lamp only and does not in any way interfere with any of the other lamps

MULTIPLE SERIES SYSTEM.

This is another system by which incandescent lamps

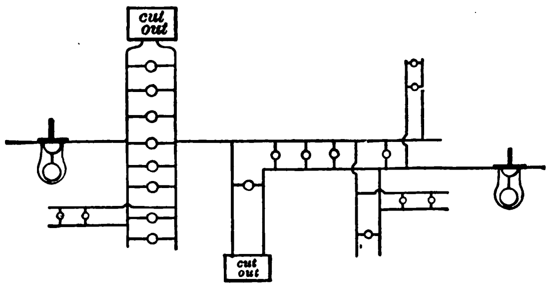


Fig. 11.—Multiple-Series System.

are used on long distance lines and is a combination of the series and multiple arc or parallel systems.

In this system the lamps are placed in parallel or multiple arc and these groups are connected to the line in series with arc lamps as shown in Fig. 11.

In this system any make of incandescent lamps may be used with very good results, the requirement being that the number of lamps be sufficient to consume the whole amount of current; as, for instance you wish to use lamps requiring one ampere and your current on the line is a ten ampere current, then you would place ten lamps in parallel in the loop and if the lamps are all of the *same resistance* they will each get the same amount of current. It is not necessary that the lamps be placed as shown in the sketch, Fig. 11, but may be placed in any position desired so that they are connected to the loop in parallel. The cut-out may be placed in any convenient position and connected to any part of the loop. Connection being made so that the wires from the cut-out are attached to the mains in multiple arc, in the same manner as the wires leading to the lamps.

The cut-outs used in this system are adjusted so that, when, from any cause, a lamp is extinguished the cut-out closes and a short circuit is made through the cut-out and a path of low resistance is offered for the current. In such a case all the lamps are extinguished, for, if the remaining lamps were allowed to burn each would receive more current than it required and would very soon burn out. The main circuit wires may be connected to any part of the parallel loop, in the same manner as the cut-out is attached. As many of these loops as are required may be connected in series, each loop having its separate cut-out, until the full capacity of the dynamo is reached.

A serious objection to this method of lighting is that all the lamps must burn if any do and all must be extinguished if one is. This renders this system impracticable for lighting dwellings or small stores where only a

single loop is used. But in larger spaces where many lamps are required the different loops may be so interwoven that if one loop is extinguished the lamps from another loop would give plenty of light until the burnt out lamp was replaced, when they could all be started again.

A good feature of this system is that the loops may be put into any part of the circuit, at any distance from the dynamo the same as an arc lamp.

Several cut-outs for the multiple series system have been devised, all answering the purpose more or less fully.

Fig. 12, shows one style of multiple-series cut-out that differs somewhat from the others, in that, instead of cutting

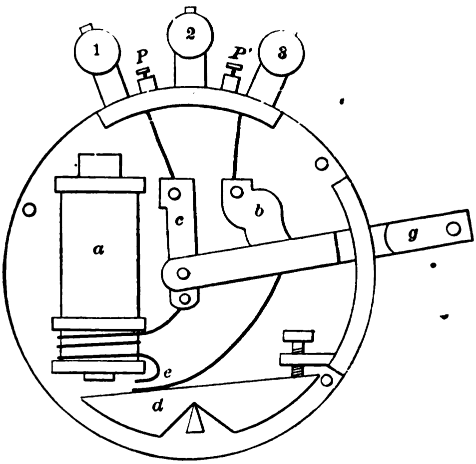


Fig. 12.—Multiple-Series Cut-Out.

out all the lamps, in case one should become extinguished, it brings three other lamps into the circuit, thus allowing all of them to burn but at a reduced candle-power.

The wires from the mains are brought to the binding-posts *P P′*.

A fine wire leading from the binding-posts to the electro-magnet forms the coil as shown at *a*. This coil, being in shunt allows a very small portion of the current to pass that way at all times; but not enough to seriously interfere with the light of the lamps. Should one lamp burn out or become extinguished from any cause, more current is forced through the fine wire of the magnet and the armature *d*, is drawn to the core. This action brings into contact the two wires at *e*, and the lamps marked 1, 2, 3, which are connected in multiple-arc to the binding-post *P*, and the plate *c*, are introduced into the circuit with the remaining lamps and the candle-power of all the lamps is reduced to such an extent that attention is called to it when the defective lamp can easily be found and replaced with a good one; then by closing the switch *g*, for an instant the armature drops, allowing the wires to separate at *e*, which cuts out of circuit the lamps 1, 2, 3, and allows the other lamps to burn at their normal brilliancy. The coarser wire leading from the plate *c*, and around the end of the core, a few turns, is for the purpose of keeping the core magnetized and retaining the armature in position while the lamps 1, 2, 3, are in circuit, otherwise the current having a path of less resistance through the lamps the armature would fall and open the circuit which would cause an arc to form between the wires at *e*, which would soon destroy the cut-out.

Another system that was devised for incandescent long distance lighting, but which has never been extensively used, is shown in Fig. 13. In this system a certain number of lamps are placed in series and each series is connected to the mains in multiple arc. Each series must be of the same resistance as each of the other series. In this way

incandescent lamps may be run at considerable distance from the dynamo with a small size of line wire. Each lamp should be provided with an automatic cut-out that will throw an equal resistance into place for each lamp that is turned off or that burns out, otherwise each lamp in the series will be extinguished by the opening

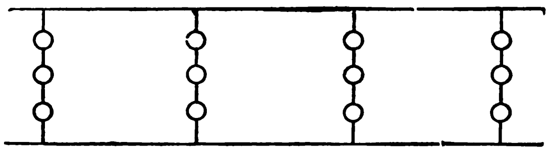


Fig. 13.—Multiple-Series System.

of the circuit. Or if the cut-out has less resistance than a lamp the other lamps would receive more current than required and soon burn out.

Another system of long-distance multiple-series lighting is shown in Fig. 14. In this system, as used by the Heisler Electric Light Company in St. Louis, six separate circuits were run direct from the collectors of the dynamo, in different directions through neighboring blocks for

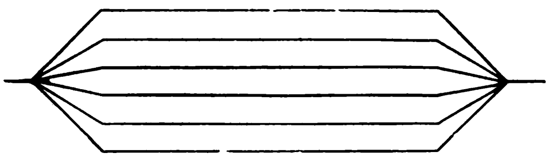


Fig. 14.—Multiple-Series System.

some distance from the station. Each circuit carries forty incandescent lamps of high candle-power, in series, and a single return wire is used for the six different branches. The resistance of the different branches is equalized by a rheostat in each branch, placed near the dynamo.

THE THREE-WIRE SYSTEM.

The three-wire system was devised for incandescent lighting over long distances, and a great saving of wire is made by the use of this system of distribution.

It is claimed, by some, that a saving of as much as sixty per cent. in the amount of wire can be made by the use of this system over that of the two-wire system. Others limit the amount saved at twenty-five per cent.

The diagram Fig. 15 will show the plan of wiring and connecting to dynamos.

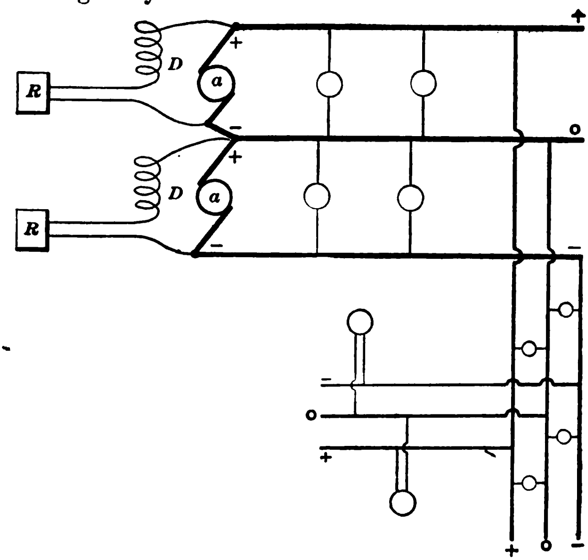


Fig. 15.—Three-Wire System.

Two dynamos are used, and they are connected in *series* to increase the e. m. f., for the object is to cover long distances and for this purpose a high e. m. f. is necessary.

The wires are led off from the dynamos as shown in the diagram. The middle wire is called the *neutral* wire, because it is neither the positive nor the negative, but it

is + to the — wire and — to the +. The two dynamos, *D D*, being in series, makes the potential equal to their combined e. m. f. Supposing the dynamos to give each 100 volts, the potential between the + and — wires would be 200 volts, and between the + and neutral wires 100 volts, and the same between the neutral and the — wires. With this potential, 100 volt lamps would be used. If the neutral wire was disconnected from the dynamos the lamps would virtually be in multiple series. You will also notice that if one dynamo should become disabled, one-half of the lamps would still be available, for they would be in parallel on one dynamo. In case of an accident of this kind, a building wired on this system would not be wholly deprived of light, for one-half of the lamps would be left burning.

By the use of the three-wire system a higher potential may be used, and smaller wire will carry the required current for a given number of lamps than would be possible on the continuous current parallel system with any lamps now in use.

In this system it is necessary that an equal number of lamps be kept in action, to maintain the balance on each side of the neutral wire, for if a number of lamps be turned on or off on either side, the resistance then being unequal, some of the lamps would burn much brighter than others.

As it is not practicable to keep an even number of lamps on each side when consumers turn on or off their lamps to suit their convenience, it becomes necessary to provide near the dynamos means by which the circuits may be kept balanced. This is usually accomplished by rheostats or resistances connected in the field circuit of the dynamos as shown at *R R*, on the diagram. By the use of these, the

current produced by either dynamo may be regulated so as to compensate for the change in the number of lamps, and in this way the circuit is kept at a balance and the lamps on both cir uits will burn with the same brilliancy.

CHAPTER VI.

THE ARC LIGHT.

When a current of electricity of sufficient volume (amperes) is passed through two carbon rods, and the points are then slightly separated, as shown in Fig. 16, a light is produced intensely brilliant and dazzlingly white, equalled only by the noonday sun in a cloudless sky. This is called the "arc" light, because the electricity, in passing between the points, does not keep to a straight line, but forms a curve or arc of a circle like this ⌒.

The arc may be formed between the points of any kind of conductor, but carbon appears to be the only substance that will give a purely *white* light, all other materials giving a light that is more or less colored by disagreeable shades. But carbon points, when they are kept at the proper distance apart, varying according to the amount of current passing, give a *pure white, steady, quiet light* that is as satisfactory as any artificial light in use. The complaints against the arc system of lighting are not made because of any fault in the *arc light* itself, neither are the lamps or systems often at fault, for the machinery is well made and quite capable of doing all that it is guaranteed to do in the way of producing a *good, steady light.* (The amount of horse power per lamp varies considerable between some of the many different "systems").

Unsteadiness of the light, hissing, flickering, flaming, blazing up, dying down, cutting out, and the various other

troubles for which the *arc light systems* are so often blamed, are seldom the fault of the systems, but, rather, the difficulties can be most frequently traced to a lack of attention to details or an insufficiency of "KNOW HOW" in the attendants.

The arc light, when it is as it is intended to be, and it is quite easy to keep it so, is represented, as well as is possible with printer's ink, in Fig. 16.

Fig. 16.—The Arc Light.

The current passes from the top carbon to the bottom one and you will notice that the upper carbon has a small depression in the end. This always forms after the light has burned a moment, and is called the "crater," on account of its resemblance to the crater of a

volcano. From this point we obtain the most light, and for that reason the positive carbon is always placed at the top in arc lamps, so that the greater amount of light may be reflected downward. The positive carbon also becomes white hot for some distance from the end, varying with the number of amperes of current passing. Some light is obtained from this incandescent portion of the carbon. The extreme end of the negative carbon also becomes white hot, and gives a small amount of light. The globe shaped aureola surrounding the points of the carbons gives a large portion of the light from the numerous dust-like particles of white hot carbon that are loosened from the end of the positive carbon, and a portion of which are vaporized in the arc. Little spots of what appear to be melted carbon appears at different places near the end of each carbon rod and from these small spots some light is obtained. The upper carbon wastes away about twice as fast as the lower carbon, and for that reason the upper carbon is made twice the length of the lower.

The distance between the points of the carbons, at which the best effects are obtained, depends upon the number of amperes of current passing, and varies between 1/32″ in twenty-two to twenty-five ampere currents, and 3/16″ to ¼″ in eight and one-half to ten ampere systems.

When the *full arc* is formed, the light is all that is desired, for then it is quiet and brilliant. For inside lighting the full glare of the arc is too intense, and should be subdued by *porcelain* or *opal* shades, which diffuse the light and subdue the shadows. Ground glass globes are not desirable for they magnify any change in the light an cast disagreeable shadows. Clear shades make the light too intense for inside use, and cast heavy black shadows.

A sketch of the shapes of carbons under three different conditions of burning may be of service.

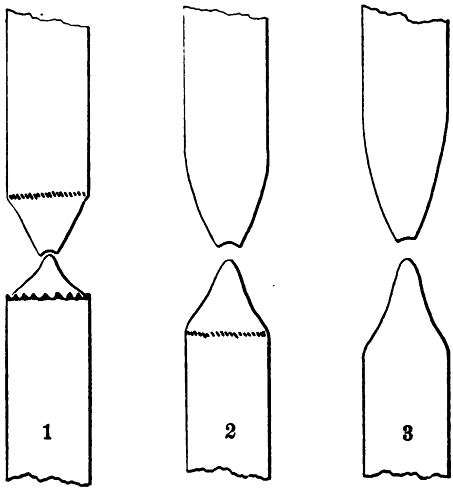


Fig. 17.

Fig. *17* shows at *1*, the shape of the carbons when the arc is too short; *2*, shows the shape of carbons when the arc is just about right; and *3*, shows the shape they will assume when the arc is too long. Examine the arc while the lamp is burning, and you can learn considerable about the actions of the lamp that cannot be ascertained as well in any other way. Use a piece of smoked or colored glass to protect the eyes.

ARC LAMPS.

To maintain a constant distance between the carbon points, which is necessary for a steady light, many different styles of lamps have been brought into use, nearly all of which will give satisfactory results if taken care of.

The details of construction vary more or less in the different makes of lamps, but the principles are similar in all, and a description of one or two will enable you to understand the others after a little examination.

REGULATING AND CUT-OUT MECHANISM OF ARC LAMPS.

Arc lamps, as far as heard from, all work on the "differential" principle, that is, a shunt of high resistance around the arc.

One style of lamp—the "Brush"—is illustrated, front view in Fig. *18*, and side view in Fig. *19*. The letters apply to same parts in both.

The action of the current on these lamps is as follows: Where the current enters, on the positive side, there are four wires, *1*, *2*, *3*, *4*, soldered together, three of them through which the current can pass while the lamp is burning. The large wires, *2* and *3*, lead to the solenoids or lifting magnets, *A A* (shown in section in cut Fig. *20*). There are two layers of these wires, and the inner end of each is soldered to the brass spool on which they are wound. These wires are connected in parallel or multiple arc.

The fine wire, *4*, is wound on outside the coarse wire, insulated from it and connected in such a manner that the current flowing through it passes in the *opposite direction* to that flowing through the coarser wire. This wire is quite small and of great length, consequently it is of high resistance, and must necessarily be so, for it is continuous from the + binding-post to the — binding-post, forming a "shunt" around the arc, leading, as it does, from the + side of the lamp into the solenoid on that side and out of there into the — solenoid, through that and into the cut-

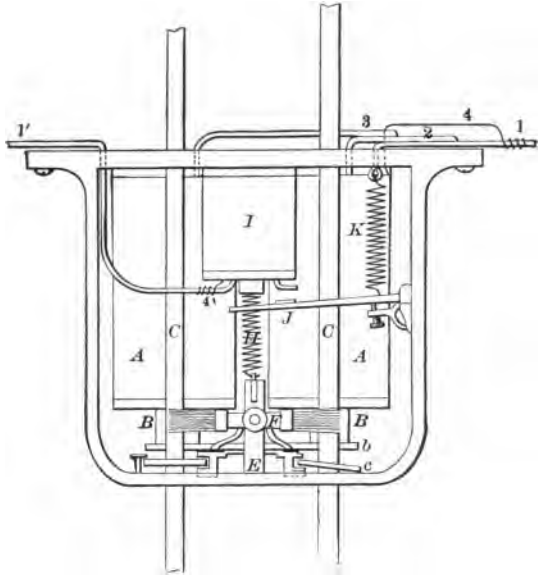


Fig. 18.—Brush Lamp, Front View.

A A, Lifting magnets or solenoids.
B B, Cores.
b, Armature.
C C, Carbon rods.
c c, Clutch.
D, Lifting lever.
F, Contact brush.
G, Dash pot.
H, Lifting spring.
I, Cut-out magnet.
J, Cut-out armature.
K, Resistance coil.

out magnet *I*, and from there it reaches the — binding-post by way of the coarse wire, as shown at *4′* (Fig. *18*), where the two wires are soldered together. This wire having such great resistance allows but a very small portion of the current, about one per cent., to pass through the shunt when the arc is at its usual length. Now, the action of the lamp (all arc lamps) is as follows: The current entering at the + binding-posts and passing through wires *2*, *3*, around the lifting magnets *A A*, through the spools to the box holding the mechanism of the lamp, then into the carbon rod, by way of the contact brushes *F*, along the rod to the upper carbon, then through the lower carbon and the frame of the lamp (not shown in the cut), by way of an insulated cable to the — binding-post and thence to the continuation of the line. The current passing through the coarse wire of the solenoids energises them, and the cores *B B* are sucked into the spools raising the lifting lever *D*, Fig. *19*, and the clutch *c*, raising the rod *C*, and separating the carbon points, forms the arc as shown in Fig. *16*.

The formation of the arc introduces a certain amount of resistance at that point, and causes a small percentage of the current to flow through the fine wire shunt, as already explained As long as the arc is of the required length the lamp burns steadily and quietly, but as the carbons wear away and the arc becomes slightly longer and consequently of greater resistance, a larger portion of the current is forced through the shunt, and the effect of this is to overcome the magnetic pull of the coarse wire coils, allowing the cores, *B B*, to settle slowly down, and the lifting lever, through its connections, loosens the clutch, the carbon rod slides slowly down, the arc is shortened,

the resistance lessened, and the amount of current passing through the shunt is decreased and the lifting magnets become a trifle stronger, and the clutch again grasps the rod and it is held stationary until the arc again lengthens, when the same changes are repeated. As long as the

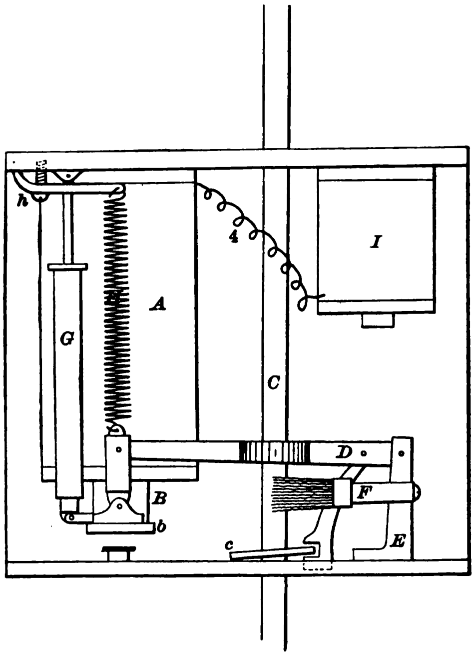


Fig. 19.—Side View of Mechanism of Arc Lamp.

mechanism of the lamp works *perfectly free*, and the arc is adjusted to the amount of current flowing, these changes will take place with such regularity that no perceptible change can be noticed in the light. It is even a difficult

matter to notice by the eye alone any change whatever in any of the mechanism of the lamp, even the cores, which have the greatest range of movement, move so little as to be scarcely perceptible when the lamp is clean and working as free as an arc lamp should.

If the mechanism of the lamp does not work with perfect freedom—especially the cores *B B*, inside the brass spools—the result will be anything but satisfactory, for should there be any hindrance to the free movement of any of the mechanism the current would not be strong enough to separate the carbons sufficient to form a full arc, and the result will be poor light for a few moments, then the light will gain strength and burn with its true brilliance and steadiness for a short time, then flame a little, and all of a sudden down it goes, away down, and then someone calls attention to *that lamp* with language more forcible than polite. Another cause of trouble in an arc lamp is a sticky rod. If the rod is sticky the lamp *cannot* work well, for there is an element working in opposition to the fine sensitiveness of the shunt and the mechanism that it controls. In the cuts, Figs. 18 and 19, you will notice that in one a double lamp is shown, while the other shows a single lamp. The electrical action in each is exactly similar, and the mechanical part differs only in the lifting lever and its connection to the annular clutches. You will notice that the hooked portion in the double lamp is double and lifts the two clutches, while in the other it is single, in the single lamp the lifting lever encircles the rod, while in the double it passes between the rods.

In the double lamp the clutches do not fit as closely on one rod as on the other. When facing the lamp, as shown

in the cut, the positive side of lamp is on the right, and the rod on that side is called the + rod, the one on the left is the negative.

In fitting the clutches to the rods, the one on the negative rod must fit enough closer than the other so that when the end of the lifting lever has raised about one-quarter of an inch from its position of rest it will commence to lift

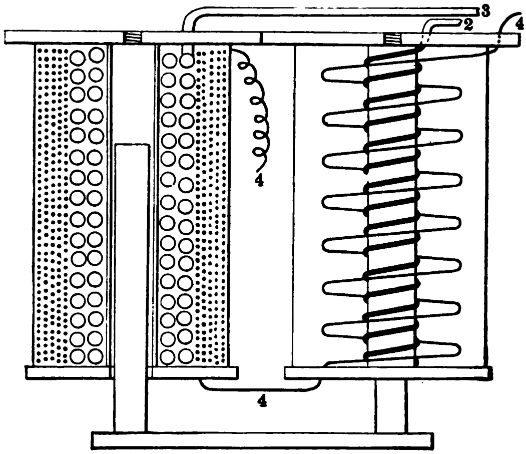


Fig. 20.

the rod; but the clutch should not catch the positive rod until the end of the lever has raised nearly one-half inch.

The reason for this is that the carbons on the negative side are separated to some distance, while the current is still passing through the carbons on the positive side and they are still in contact. This arrangement causes the arc to form on the + side when the current is first turned on and if the adjustment is about right that side alone will burn until the carbons are fully consumed. As soon as

this takes place the flow of current through the shunt increases, and the armature settles down sufficient to allow the negative carbons to come together, when the flow of current changes to the negative side and an arc is immediately formed there.

If the clutches are not correctly fitted to the rods, or if the adjustment of arc is not right, the arc will change from side to side, and an unsatisfactory light will be the result. The annular clutch is simply a brass washer about $1\frac{1}{8}''$ outside diameter and $^{15}/_{32}''$ inside diameter and $^{3}/_{32}''$ thick.

In case the lamp works badly and the rod does not feed down, the resistance of the arc becomes so great that an extra amount of current is forced through the shunt, and soon causes a sufficient magnetism in the cut-out magnet *I* to attract the armature *J*, which completes a short circuit of low resistance through the wire 1 (Fig 18), the resistance coil *K*, the armature *J*, the coarse wire of the cut-out magnet *I*, and on through the wire 1′ to the — binding-post. This short circuit takes the current from the solenoids, and by throwing them out of action will allow the rod to feed down if it is not stuck fast. Should the rod feed down and the carbons come together, then the path of *least resistance* for the current is through the lifting magnets and on through the carbons, for the coil *K* offers more resistance than the other path, and as soon as the circuit is complete through the carbons the armature *J* falls, the lamp starts up, and the arc again forms.

In some styles of lamps, when the cut-out acts, the lamp does not start up again, even if the carbons do come together, until the switch has been closed and opened

again, the makers claiming that it is better to know if a lamp is in bad order and have it repaired at once than to leave a faulty lamp in circuit to annoy the persons depending on it.

In the lamp we are describing several reasons will be found for the rods sticking, and while this seldom occurs, it is well to know the causes and their remedy. One source of the trouble is a bent rod. If the rod be bent by careless handling, or in any other manner, it will frequently cause the rod to stick so that it will fail to feed. If the rod, when pushed up, strikes against the chimney it will cause the rod to stick and if the lamp does not remain cut out it will at least burn badly. Another reason for this trouble will be found in particles of fine wire becoming broken or burnt off the contact brushes and falling into the clutch, wedging the rod so it cannot feed. The remedy for this last is to keep the brushes in *good contact* with the rod, yet not too tight, and if the fine wires become badly bent throw the brush away and replace it with a new one.

If the pressure of the brush *F* on the rod is not sufficient to produce good contact, small arcs will be formed between the rod and brush, which will cause burnt spots on the rod, and will also burn the fine wires of which the brush is formed.

The dash pots, *G*, in lamps are for the purpose of preventing any sudden movement in the mechanism. The rod of the dash pot sometimes causes the lamp to act badly by becoming corroded where it passes through the cap. A notch sometimes forms in the rod, at this place, through corrosive action and wear that is quite sufficient to prevent its free action and this simple thing, as well as anything

else that prevents the absolutely free action of *any part* of the mechanism of a lamp, will cause an unsatisfactory light.

The length of arc may be regulated by the adjusting screw *h*, and the lifting spring *H* which assists the current in lifting the weight of the armature and cores.

Loose contacts in any part of the circuit about a lamp will surely cause trouble.

Cables, which are made of very fine wires and covered with insulation, often cause trouble by an end of wire working through the covering and coming in contact with some part of the lamp and making a short circuit for a portion of the current. This occasionally occurs, and it is sometimes a difficult matter to locate the fault, but it can be done by disconnecting one wire after another and testing after each connection is broken until the fault is located. Of course, you will understand that the lamp must be out of the circuit when testing for short circuits.

It would be a difficult matter to describe, in detail, the different arc lamps that are in general use at the present time, but there are the same *principles* in all, though the details vary more or less in each system. In one style of lamp there will be four hollow magnets or solenoids; two will be wound with coarse wire to do the lifting, and two others wound with fine wire and connected in shunt to act in opposition to the coarse wire magnets, and through the mechanism produce the feed.

Other lamps have but two magnets, one coarse and one fine wire. All arc lamps have, or should have, a cut-out to close a short circuit through the lamp if the carbon rods become stuck, or for any reason fail to feed down when the arc becomes dangerously long. The cut-out in some lamps

depends on coils of higher resistance than that of the demagnetizing or shunt coils, and only act when the shunt coils fail to cause the carbons to feed.

Let me say here that these shunt coils of high resistance, which allow only a small portion of the current to flow through them, are made up of a very great number of turns, and the magnetic effect is greater than that of the coarse wire magnet of few turns and more current flowing. To make this fact more plain, let us suppose that in one case there are fifty turns of wire on the spool and eight amperes of current flowing through, then there would be fifty times eight or four hundred *ampere turns*, and the strength of the magnet would be that due to 400 ampere turns. Now, the fine wire coil may have 5,000 turns and be of such resistance that only one per cent. of the current or eight one hundreths of an ampere will flow through. Such being the case, we multiply 5,000 by .08, and that gives us 400 ampere turns and a magnetic strength equal to what we have in the coarse wire coil. And this is what we want *when the arc is of the right length.* Any slight difference from this *balance* may be regulated by the lifting spring and adjusting screw. The coils do not have as much resistance as that mentioned above, the figures used are given merely to illustrate the idea.

As the arc grows longer, it necessarily offers greater resistance and less current passes that way, and more current passes through the fine wire coils.

THE CLOCK-WORK LAMP.

Another style of lamp is the clock-work lamp, differing from the others in no essential point except that the feed of the carbon rod is regulated by a train of gearing

instead of by a clutch. In this style of lamp (Fig. 21), the rod *C* has a rack (or serrations) on one side that engages with a small toothed wheel or pinion that is on the same shaft with a larger wheel that engages with another pinion and wheel that connects to a small fan *f*.

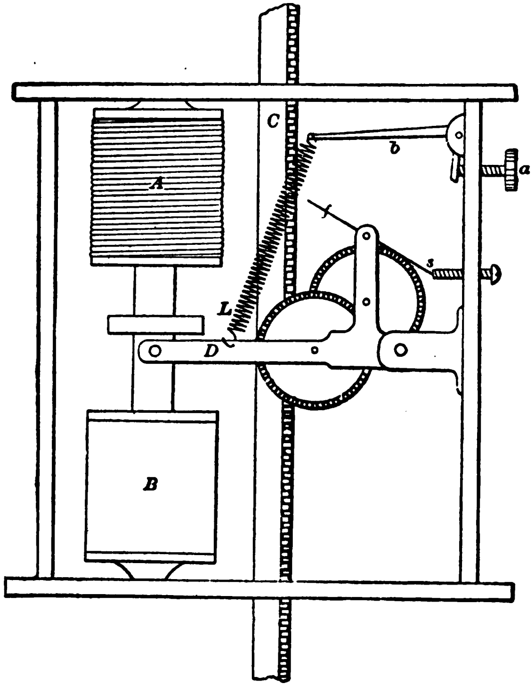


Fig. 21.

The action of this lamp may be explained as follows: The current being turned on to the lamp the coarse wire magnet *A* is energized and lifts the armature and the bar *D*, which carries the train of gearing and the end of the fan *f* comes in contact with the end of the screw *s*. This

prevents any farther rotation of the gearing and the farther movement of the lever *D* lifts the carbon rod, and the arc is formed.

When the arc becomes too long, current is shunted through the fine wire magnet *B*, the lever is pulled down sufficient to allow the fan to pass the stop *s*, the rod then feeds a notch or two, which shortens the arc and lessens its resistance, and the current ceases to flow so strongly through the fine wire, which allows the lever *D* to raise sufficiently to bring the fan again in contact with the stop *s*. The length of arc is regulated by the adjusting screw *a*, the lever *b*, and the lifting spring *L*, the same as in the other style of lamp shown in Figs. 18 and 19. There is but very little choice in the different styles or makes of arc lamps, as they will, one and all, give satisfactory results if kept clean and in good order.

There are arc lamps having peculiarities of their own, but as the principles do not differ in any material point from the ones described, it is not considered necessary to illustrate them, as all contain the lifting magnets or solenoids, a clutch of some kind, and the shunt coil of high resistance. A description of one will give a very good understanding of the workings of all.

CHAPTER VII.

COMMUTATORS AND BRUSHES.

The commutator or collector of a dynamo is used for changing the alternating currents, as produced in the armature, to continuous currents, as delivered to the lines. You will remember that in the description of how the cur-

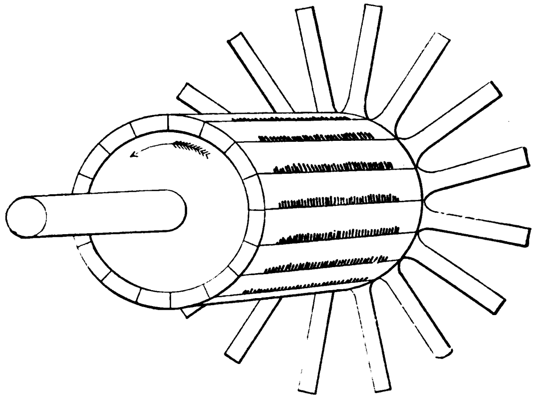


Fig. 22.—Multiple Segment Commutator.

rent is produced, it was shown that in each bobbin of wire in the armature a current in one direction was produced when passing one field magnet, and a current in the opposite direction was generated when passing under the influence of the other field. The commutator transfers these

currents, as they are formed, to the brushes, which convey them to the lines continuously in one direction. In the commutator and brushes will be found the greater part of the difficulties that the engineer in charge of a dynamo has to contend with in his electric light plant, but a little attention to the brushes will generally overcome all the difficulties. If you have a machine that is defective in build, why then, of course, you can not make it work satisfactorily with any amount of attention. Defective dynamos are not now turned out by any of the old companies, so it will not do to suppose that they are defective in any way until all the points necessary to their good working condition have been thorougly attended to.

The commutator shown in Fig. 22 is a representation of a class of commutators used by many different builders, differing only in the number of sections, the kind of insulation used, and the method of making the connection to the armature wires. An explanation of the construction of a similar commutator was given when describing Fig. 2. It is an excellent working commutator, and answers every purpose.

The commutator shown in Fig. 23 is the style used on the Thompson-Houston arc light dynamos, and has three segments, to which are connected the outer ends of the armature coils, three in number. The framework of this commutator is, of course, insulated from the shaft, and the wires are brought outside the shaft bearing through the center of the shaft, which is hollow, for some distance from the end. The construction of this commutator is such that it is seldom necessary to do any fitting to the segments farther than to merely attach them with screws.

The commutator used on the machines (arc, incandescent and motors) of the Brush system, is shown in Fig. 24. The inner part is of wood, bored to fit the shaft; outside of this is wound a number of layers of varnished paper, and on this, brass segments are fastened by screws which take hold in the wooden core. These brass segments are separated about ¼ inch from each other, and require no insulation between, except the air space, which is an excellent insulation of itself.

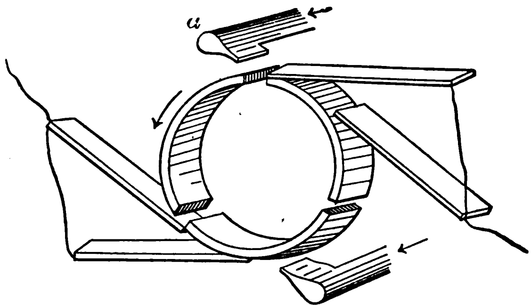


Fig. 23.—Three-Segment Commutator, Brushes and air Blast of Thompson-Houston Arc Dynamo.

The wires from the armature are led through the hollow of the shaft to the outside of the journal, where they are soldered to wires that connect with the segments of the commutator.

The copper segments that receive the wear of the brushes are attached to the brass pieces by screws and can be easily removed or replaced with new ones.

The same may be said of all commutator segments that require to be changed occasionally.

The Brush commutator has either eight or twelve sections, eight on the smaller and twelve on the larger

machines, and use four or six brushes, according as there are two or three divisions of the commutator. Each division carries four segments, and these segments are not connected to armature bobbins that immediately follow each other, but, in the smaller machines, to every second bobbin, and in the larger machines, every third bobbin. Each of the divisions are similarly connected, and each brush is in contact with two segments two-thirds of the time.

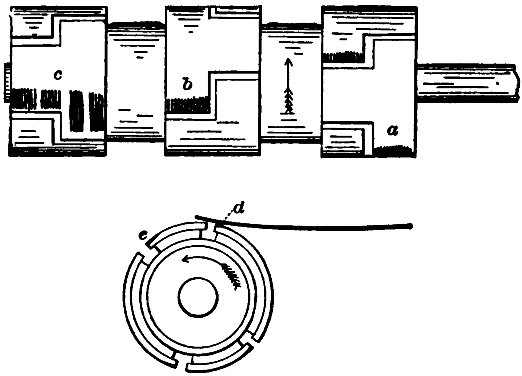


Fig. 24.—Brush Commutator, Side and End Views.

The commutators here shown cover the principles of all the various styles of commutators on arc or incandesent dynamos, or motors of the two pole type.

The care of a commutator is a very simple thing after the commutator is once put in *good order*, as it usually is when new, and should run for an extended length of time if it is given a very little attention at the right time. Our experience has taught us a few things to be observed and attended to as soon as noticed, and we found that our

troubles were directly proportioned to the length of time we allowed to pass between the instant when we first notice an indication of trouble and the time when we remove the cause of it. Oils, grease, commutator compounds, and all substances of a like nature, we have found were *not necessary* to the smooth running of a commutator if other things were taken fully into consideration and acted upon; for the principal cause of commutator troubles will be found to have its origin in the brushes.

BRUSHES.

The different styles of brushes used on the various makes of dynamos and motors may be illustrated by the three brushes shown in Fig. 25, and marked *a*, *b* and *c*. The

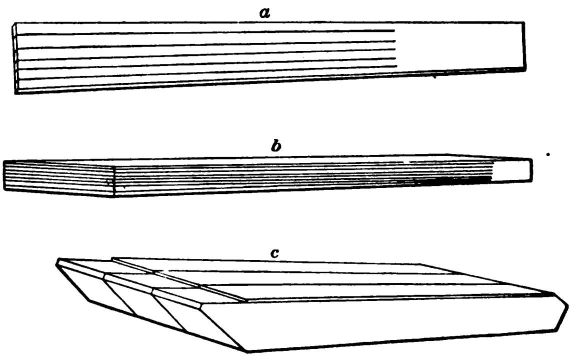


Fig. 25.—Different Styles of Brushes.

brush marked *a*, is of rolled copper, about 1/32″ thick, varying in length from 8″ to 12″, and in width from 1¼″ to 3½″, according to the machine they are used on. These brushes are usually set so that the extreme end does not touch the commutator segments, but the bearing is slightly

back from the end. It is set to project over in this manner to prevent the end from catching on the segments if the machine is, from any cause, rotated backward. This seems an unnecessary precaution, and is wasteful of brushes, for when set to project over in this manner and they become badly worn, it is necessary to trim off fully twice as much as would be required if they had been set so as to give just enough contact. This style of brush will be found on the Brush machines of all kinds, and on the Thompson-Houston arc dynamo. Brushes of this kind are quite hard, and it is necessary that they should be so, in order that they may be stiff enough to give them the amount of pressure thought to be required to keep the machine from *flashing*.

The brush marked *b*, is composed of very thin strips of rolled copper, and varies considerably in the number of layers necessary to produce a brush of the required thickness. One end of the pile of strips is soldered together for convenience in handling. These brushes are often hard enough to make trouble.

The brush shown at *c*, is composed of soft copper wires and strips of soft sheet copper laid into the form represented in the cut. Being soft, as they are, they produce no unnecessary wear on the commutator, and no lubricant is ever necessary to prevent them from cutting the commutator if they are not allowed to wear until the face in contact becomes too broad.

Some dynamos require four brushes set at different points on the commutator, as shown in Figs. 23 and 26; this is required on the machines to which they are applied to prevent excessive sparking at the brushes in some cases, and in another case, to keep all of the armature

bobbins in closed circuit while in a position to generate a current. One dynamo that we have seen, but never had any experience with, is encumbered with *eight* brushes, and they, each and all, serve a purpose—and it is a very good dynamo too.

The brushes shown in Fig. 26, are similar to those shown at *b*, Fig. 25, but made of heavier material, and on

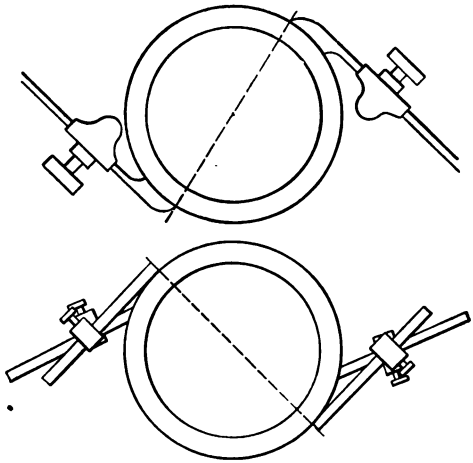


Fig. 26.—Double Brushes.

one dynamo the brushes used are curved downward as shown in Fig. 26.

Brushes of the kind shown at *a*, Fig. 25, are usually set in contact with the commutator, as shown in Fig. 27. Brushes like *b* and *c* are set as shown in Fig. 28, *a*, which shows the correct position for all brushes of this kind.

In our experience with dynamos, both arc and incandescent, and with motors, we have found that certain

causes always show themselves by certain effects, and the following list of

TROUBLES WITH COMMUTATORS AND BRUSHES,

and their remedy, may be found of interest in helping you to care for your machines with less anxiety to yourself and greater satisfaction to those depending on the light.

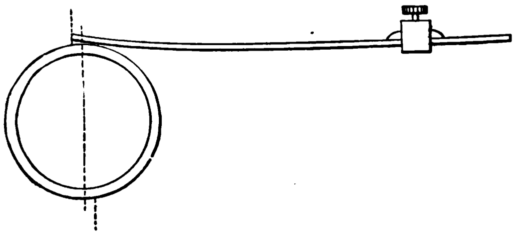


Fig. 27.—Correct Position of Brush.

SPARKING AT THE BRUSHES.—Some styles of dynamos will spark at the brushes in spite of anything the attendant can do to prevent it, but many other styles of dynamos can be run with absolutely no sparks on the commutator. The first point to be attended to is to get your commutator perfectly smooth, or as near it as possible, with the means at your command, for if the commutator is not true you cannot prevent sparking at the brushes.

If you have a slide-rest, use it, and get your commutator round and true from end to end. If you have no slide-rest, a 16″ bastard file will do nearly as well. Take the brushes and brush-holders off, so that you may have plenty of room to work. Start the dynamo to turning very slowly. Hold a piece of chalk so near the commutator that it will mark all of the high spots. Move the chalk slowly from end to end of the commutator, so that all high

places on the full length will be chalked. Stop the dynamo and amuse yourself filing off those parts that have been marked by the chalk. If you have noticed while the dynamo was turning about how much the commutator was "out" you can easily tell about how much you will have to file away to bring it true. File off all the places that have been marked, and then start up again, slowly, and chalk it again. Repeat the chalking and filing until the commutator is quite round, and of the same size from end to end.

Next get a piece of shingle, thin board, or a piece of lath, even, will do, and wrap a sheet of No. 00. *sand-paper* around it—never use emery paper or emery cloth—for the emery is liable to get caught between the segments and make a short circuit. The particles of sand will not cause a short circuit even if they should become wedged between segments. Start the dynamo at a pretty lively speed, and smooth the commutator down with the sand-paper, holding the flat side against the work. It is not necessary to work it down to a *polished* surface, although it would be well if it were polished. Now that you have your commutator round and smooth—and it must be so smooth that there are none of the marks (such as are shown in Fig. 22) left on the commutator, for the same cause that produced them will certainly make more trouble if they are not removed.

Now that you know your commutator is in good shape, proceed to set your brushes as shown in the cut that represents the kind of brush you use, being certain that the points of opposite brushes are diametrically opposite, as shown by dotted lines in Figs. 26 and 27, and at *a*, in Fig. 28, but *do not* set them as shown at *b* and *c* in same

figure, for if you do set them in such positions they will be sure to spark and will eat out the commutator in a manner similar to that shown in Figs. 22 and 24, *a*. The pressure

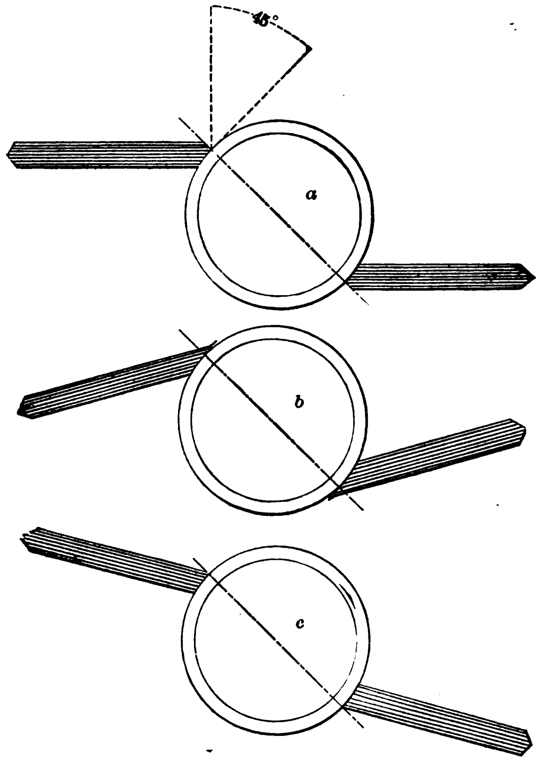


Fig. 28.—a, Correct Position; b, too much Contact; c, Very Bad Position.

put on the brushes need be only just sufficient to make *good contact*. It is not necessary to have much pressure to preserve good contact. Should the contact be too slight

it will make itself known by a peculiar noise that is indescribable, being neither a snap, crack or pop, and yet might be called by either of these names. You may be sure that the noise will call your attention if you are anywhere near, and after you have once noticed it you will easily recognize it the next time. This noise and considerable sparking will always be present when the brushes do not press heavily enough upon the commutator.

If the brushes are not set with the points directly opposite, sparking will result.

If the brushes are set ahead of the neutral line or back of it they will spark.

When setting four brushes on a commutator that requires two brushes side by side, it is sometimes difficult to get all four of them of an equal length, or evenly divided on the commutator, one or more of them will spark more or less. After rocking the brushes back and forth a trifle to find the point of least sparking, you can then tell by the color of the spark whether the brush should be lengthened or shortened. When the spark is of a decidedly greenish color the brush is too short, but if the spark appears to spatter and shows a reddish hue, then you will find that the brush is too long, or is so worn that there is too much of it in contact. By the way, you will find more trouble arising from having too much of the brush in contact, than from having too little.

Cutting of commutator, scratching and eating away of the segments, is mostly due to the brushes having too much surface in contact, and increase of surface requires increase of pressure to prevent sparking, and too much pressure will wear away the commutator, and having too much of the face of the brush in contact will cause an edge of the

segments to become eaten away (as shown in Fig. 22), and if not attended to, the commutator will, in a very short time, become as rough as a corduroy road.

With the thicker style of brushes (*b*, *c*, Fig. 25) we have never found it necessary, even when running at full load, to have more than one-third of the full end surface of the brush in contact with the commutator, and farther, we have found that if we allowed the brush to become so worn that even one-half of the end surface bore on the segments it would cause sparking.

To prevent the necessity for filing the brushes every day (which would be wasteful), to keep them in the best of order, we found that they could, with great advantage, be turned the other side up and allowed to wear in that way until the surface in contact became too great. This resulted in getting more than twice the amount of work out of a brush than was possible by filing always from one side, or trimming the ends square as often as they became badly worn. If the commutator becomes very hot you will be quite sure to find that your brushes are badly worn or press too hard.

Flat spots on the commutator, frequently explained by laying it to soft spots in the copper, we have always found to result from an entirely different cause. When the marks have the appearance of a blow from the pene of a hammer, it will generally be found to be caused by a loosely connected or badly soldered armature wire connection. A spot of this kind continues to grow larger until the cause of it is removed and the commutator dressed down smooth.

At the end of the segments a spark or stream of fire encircling the whole commutator will sometimes be noticed.

This *may* be caused by an accumulation of oil or copper-dust or dirt, that causes a short circuit, as generally accounted for, but it will, in most cases, be found that the insulation is charred or burned through at some place near where the spark is noticed, and if a careful examination of the armature wires are made you will find that a connection is loose or has very poor conductivity. Allowing the commutator to run hot will increase difficulties of this kind. Mention has been made of one or two causes for the commutator running hot.

A dynamo that had been acting very badly for some time, carrying sparks in unusual places, and the commutator getting so hot that when an oiled rag was applied to stop the cutting a cloud of smoke would arise that was alarming, was found to have nearly every strip of insulation between the segments burned through in several places, and many of the burnt places were merely small holes about the size that a pin would make. The insulation was mica. The cause of this was found to be a very serious case of neglect, aggravated by a lack of knowledge of how to care for a commutator. The segments were exceedingly rough, having been eaten away similar to that shown in Fig. 22, but considerably worse. One brush was forcibly held into contact by a wooden brace, one end resting on the frame of the dynamo and the other end forced under the outer end of the brush. One brush on the opposite side was held in contact by a spring fastened to the floor and attached to the brush.

The man in charge of this dynamo, who of course called himself an electrician, had a commutator compound which he considered all that was necessary to keep the commutator in good order, as he never smoothed the

commutator with a file or sand paper, relying on his ability to place the brushes in a position to wear the commutator evenly.

When the armature was repaired, it was found that the solder on several of the connections had been melted away entirely. Had a piece of sand paper been used two or three times a week to keep the commutator smooth, it would have saved a large bill for repairs, saved brushes, saved power, and saved the attendant a great deal of time and unnecessary trouble.

Another case of relying too much on commutator compounds, and not keeping the brushes in good order, resulted in a badly burned-out armature. Many cases of the same kind have been noticed where the armature has been badly injured by a lack of attention to the commutator and brushes.

A large majority of the armatures that come to the repair shop have no other injury than that which has been caused by lack of care with brushes and commutators.

The burning out of armature windings has frequently been shown to have its primary cause in a rough or uneven commutator, causing a break of contact between it and the brushes at a wrong position, or if sufficient pressure is used to keep the brushes in enough contact to prevent this, then the danger of *too much* contact presents itself, and this will cause short circuiting that will heat the armature wires so that the insulation will become charred, and a short circuit will be the result, and a short circuit in the commutator soon results in a burnt armature.

Another difficulty between commutator and brushes will be found illustrated in Fig. 24, where the commutator is eaten away by the erosive action of the current, as

shown at *a*, *b* and *c*, each differing in the extent of the erosion.

This will be found to result from the brush being lifted up from one segment by the following segment, a bad case of which, though not exaggerated, is shown at c. Although the commutator may have been turned in the lathe and the copper segments turned true, still you will find that the copper segments often are sprung slightly when fastened on, and while being but very little out of true, will cause but slight eating away as shown at *a*, but if not remedied will continue to get worse and worse, and heating of segments and armature wires will result.

A slight aggravation of this difficulty will produce a result as represented at *b*, and may become as bad as shown at *c*. A commutator allowed to work in this condition will surely produce great heating in the armature, and may result in burned insulation and short-circuited coils.

To remedy this difficulty the *leading* portion of the *following* segment should be filed off, as shown at *e;* this will allow the brush to remain in contact with the segment until its *full length* has passed under the brush. Otherwise the brush will be lifted off (as shown in the end view), and an arc will be formed between brush and segment that will cut away the segment very fast. After fitting new segments of this kind it is well to try their truth with a piece of chalk, and file down any high places that may be found. If the leading edge of each segment is eased off for about $\frac{1}{8}''$ back it will result in much better wear, and both commutator and brushes will last much longer.

The SCRATCHING and CUTTING of commutators is most frequently caused by the brushes being too hard. Where brushes of the style *a*, Fig. 25, are used, it is *always* neces-

sary to use some oil to prevent cutting away of the segments by friction.

Considerable difference will be noticed between the wear of the commutator from the brushes being too hard and that due to the erosive action of the current where small arcs are formed between commutator and brush. Where the brushes are too hard, the wear is due to friction, but where the brushes are not properly set, or have become so badly worn that they cover too much of the commutator, as is frequently the case with brushes like *b*, *c*, Fig. 25, the greater part of the wear will be found to result from the action of the current. This action is similar to that which causes the positive carbon of a lamp to wear away twice as fast as the negative carbon for the current is in a similar direction. If any kind of brush is used with too much pressure on the commutator, it will cause cutting from *friction*, so it is always better to set the brushes with just enough pressure to carry the current.

The Thompson-Houston arc dynamos have an air blast that forces a jet of air against the point of the brushes, which assists, materially, in keeping down the sparks and cooling the commutator, which is quite an advantage. A small amount of oil is forced through with the air, and this keeps the commutator well lubricated.

With brushes of the kind marked *a*, we have obtained excellent results in reducing the sparking until it was almost *entirely* overcome, and the wear of the commutator reduced to a minimum, by placing two or three thicknesses of thin, *soft* copper *under the brushes* and extending from clamp to end of brush.

This brought all the wear on the soft copper strips, and the brushes acted as springs to hold the soft copper in

contact. This arrangement produced entirely satisfactory results, for the sparks were made so small as to be barely noticed, and the commutator received that dark brown, glazed surface that shows that first-class results are being obtained, and very much less attention to commutator and brushes was required, as no dressing down of the commutator was required for more than three months' run of eight hours per day. This was on a dynamo running 40 arc-lamps.

FLASHING OF DYNAMOS.

Numerous causes have been assigned for this annoyance, but as many of them were the results of faulty construction, we will not consider them here, for at the present time all dynamos of any note as at present constructed leave no chance for flashing to occur and if it does occur something will be found to be out of order.

If the dynamo flashes you will be most apt to find that the brushes are out of position. Either too far ahead or too far back, or not set diametrically opposite each other. If brushes do not have sufficient pressure to bring them into the necessary contact, a machine will frequently flash.

Another cause for this difficulty will be found in a hot commutator. The vapor formed from oil or the alcohol used in the shellac, where shellac is used on a commutator, becomes a very good conductor when heated. We once experienced two weeks of soul harrowing annoyance from an arc dynamo that had always had a bad reputation for flashing and burning out commutators, but fully realizing that there was a cause for everything, and not taking any stock in mysteries, we tackled the problem and eventually located the cause. From the peculiar action of that

dynamo, all kind of theories were built up to explain it, and every part of the dynamo was repeatedly examined for faults, and every test suggested was tried with no benefit. A swinging ground on the line was indicated, and everything appeared to point to that as being the cause of the trouble.

Considerable time was spent in looking for a swinging contact. One night a very thin smoke was seen rising from the commutator, which could be noticed only when the light was at a certain angle, and while looking at it the flashing commenced again, and the commutator caught fire before the current could be turned off.

An examination showed that the commutator was very hot, and the shaft also, though the shaft bearing was not noticeably warm, until a small spot on the bottom bearing was found that was quite hot.

The box having wooden liners prevented the upper portion from becoming warm until the shaft had become hot enough to cause trouble, and the boxing coming so close to the commutator gave no chance for placing the hand on the shaft.

Since that experience we have been able to easily locate the mysterious cause of flashing on several dynamos of the same build and on two of a different type.

CHAPTER VIII.

CURRENT REGULATION.

In the regulation of current on arc light circuits, or where the work is in series, the object is to keep the amperes of current the same at all times, and vary the potential as the work requires.

In the parallel or multiple-arc and three-wire systems, it is necessary to keep the potential constant, while the amperes of current vary as the work demands.

The current produced in a dynamo depends upon the amount of magnetism or lines of force in the field, the length of wire in the armature and the speed at which the armature wire cuts the lines of force. So it is evident that the current may be varied by changes made in any one or more of these factors, as, for instance, if the magnetism of the fields is increased, an increase of current will be produced, and a decrease of magnetism will result in a decrease of current.

Any change in the speed will produce similar results, or if the length of wire on the armature that is cutting lines of force be increased or decreased, the speed and magnetism remaining the same, the current will change in very nearly the same ratio. There is still another method of regulating the current, depending on a different principle from those mentioned above. You will remember that we explained in an earlier part of this book that there was

a point of higher potential on the commutator, at which the brushes were usually set. If the brushes are changed from this position, a change in the current will result. This method of regulation has been employed on several arc light dynamos, and is still in use on some. Where the regulation of current by a change of position of the brushes is produced automatically, the result is quite satisfactory. If but two single brushes alone are used, there is generally considerable sparking at the brushes, while if the brushes be doubled, or make contact at four different places on the commutator, the sparking may be entirely subdued. With a commutator of few segments, it is not practically possible to wholly avoid the sparking, when regulating by the brushes alone.

In speaking of the regulation of the electric current, we must always consider two things: The e. m. f., or potential, and the amperes, or quantity. The amperes are the result of e. m. f. through resistance. It has been said that electromotive force is the only quality which the electric current possesses, and a little study of the subject, with the points already given, may enable you to comprehend it. So you will understand that the regulation of current in either system depends on the regulation of the e. m. f.

HAND REGULATION.

This may be produced, on some dynamos, by moving the brushes on the commutator to positions of higher or lower potential. On other dynamos this method will result in producing much sparking at the brushes, without any great change in the current.

Dynamos having much space between the pole-pieces require the greatest change in the position of the brushes

for any change in the load on the machine; while dynamos whose pole-pieces come nearer together require less change.

One make of dynamo, which we have handled, required no change whatever in the lead of the brushes, even when the load was varied 90 per cent., as was done nearly every night. In this dynamo the pole-pieces were unusually close together.

On other dynamos, where there was considerable space between the pole-pieces, we found it necessary to move the brushes for every slight change in the number of lamps.

You may have gathered from what has already been said that the point of commutation on the commutator lies at that point which is in contact with the section of armature wire, which is in position between the poles; that is, at some part of the space separating the pole-pieces. The exact location of this point may vary somewhat in different machines, due to local causes, but the change required in the position of the brushes, for variations in the load, will be found to correspond very closely to the distance between the pole-pieces, when reduced to compare with the size of the commutator.

BY VARYING THE INTENSITY OF THE FIELD.

A rheostat or set of resistance coils is introduced into any part of the field circuit of shunt wound dynamos, and the current may be varied to any extent within the capacity of the dynamo by introducing more or less of the resistance.

The usual form of these regulators is shown in Fig. 29

This is an outside view and will apply to many different kinds. The interior arrangement differs in form and material used. In some, the resistance is iron wire wound in open coil—the same as an open coil spring. In others,

German silver wire is used, and it may be wound in open coil, similar to the above, or wound on an open rack or reel with an air space between the wires, and in others you may find insulated wires of any metal having a high resistance wound in close coil on a spool. In the latter case, the wire is generally wound double. This is done to prevent self induction in the wire. If the insulated wire was wound in close coil and continuously on the spool,

Fig. 29.—Resistance Box for Hand Regulation.

there would be self induction between each turn of the wire; but where it is wound double the current is passing in opposite directions through the turns touching each other, thus preventing self induction. Referring to Fig. 29, you will notice that there is a circle composed of small strips of brass, slightly separated by air spaces. A lever extending from the centre of the circle, makes contact with these pieces through a flat spring of sheet brass. The resistance coils are connected to the strips in the manner shown in Fig. 30. The first strip on the regulator is con-

nected to one binding post by a short wire, and one end of the first coil is also soldered to this strip; the other end of the coil and one end of the second coil are soldered to the next strip, and the remaining coils are connected in the same manner. This arrangement places the coils in series. A wire makes connection between the pivot of the lever and the other binding post. This regulator may be introduced into any part of the field circuit, the ends of the field wire being connected to the binding posts.

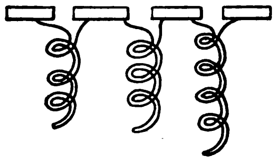


Fig. 30.—Resistance Coils.

By moving the lever around the circle, coil after coil of resistance is thrown into the field circuit, thus furnishing an easy method of regulating the current to any intensity desired. In using this regulator, all of the resistance is usually thrown in when starting the dynamo, and it is necessary to throw it out gradually, allowing the current to build up slowly. After the current is brought to the proper intensity, very little change in the regulator is required to compensate for the changes in the load on the dynamo.

CHAPTER IX.

THE AMERICAN SYSTEM OF AUTOMATIC CURRENT REGULATION.

The American dynamo is of the gramme type, having the ring armature, wound in closed circuit. The commutator is of the common style. Four brushes, held by two brush holders, (Fig. 26) make contact at four separate points on the commutator. The field coils are in series. In this system the regulation of the current is produced by changing the position of the brushes. This is effected automatically by the regulator shown (end view) in Fig. 31. The method of its action can be easily understood from the following description: The solenoids *S S* are connected directly in the circuit, the full current passing through them, and when the current is at the proper potential, the pull of the solenoids, acting against the retractile spring *f*, is just sufficient to hold the lever *c* midway between the stops *s s*. The wheel *a* (shown by dotted line) is keyed to the end of the armature shaft. The friction wheel *b* has two rims on the back side, between which the small wheel *a* revolves. This wheel *b* is pivoted to the short arm of the lever *c*, and carries a pinion which works in the gear wheel *d*, and this is geared to the wheel *e*, its shaft extending through the frame and carrying on its opposite end a pinion which engages with

another gear wheel attached to the yoke that carries the brush holders. If the current should become too strong, the solenoids would attract the armature, raising the lever

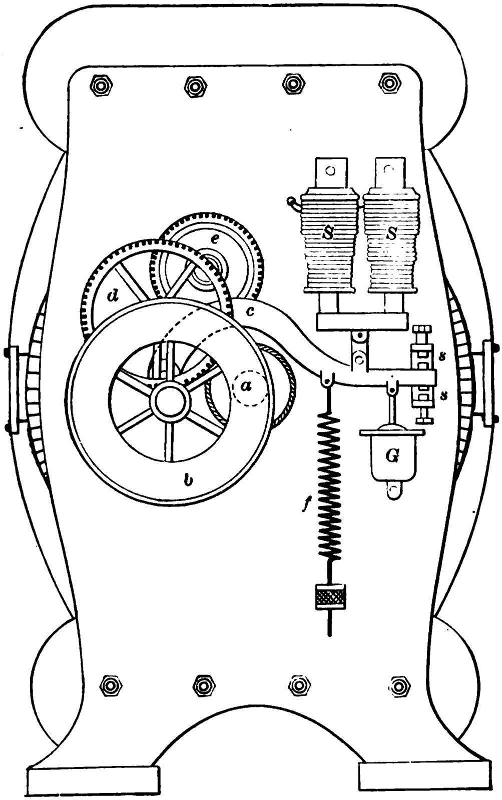


Fig. 31.—Regulator of American System.

c. This would move the wheel *b* to the right, bringing its inner rim against the wheel *a*; this would cause the wheel *b* to revolve and communicate its motion, through the

gearing, to the yoke and move the brushes on the commutator to a point of less potential. When the current is reduced to its normal amount, the spring pulls the lever down sufficient to remove the contact between the wheel *a* and the rim of the wheel *b*, which then stops turning and leaves the brushes in their new position until another change in the current acts on the lever.

Should more work be thrown on the dynamo the current would be lessened, weakening the power of the solenoids and allowing the spring to pull the lever down. This would bring the outer rim of the wheel *b* into contact with the wheel *a*, and the wheel *b* would revolve in the opposite direction. This would move the brushes to a position of higher potential and the current would be increased. The dash pot *g*, which contains a piston working nearly air tight, serves to prevent any sudden movement of the lever. The regulator may be adjusted to give any desired number of amperes on the line by varying the tension of the spring *f*. The screws *s s* serve to adjust the throw of the lever to produce the required friction between the wheels *a* and *b*.

CHAPTER X.

BRUSH SYSTEM OF AUTOMATIC CURRENT REGULATION.

The "Brush" system, named after its inventor, Chas. F. Brush, presents features peculiarly its own. The armature, a gramme ring (Fig. 32), has a core built up of hoop

Fig. 32.—Brush Armature.

iron, with strips laid in crosswise, leaving spaces in which the armature coils are wound. The inner ends of opposite

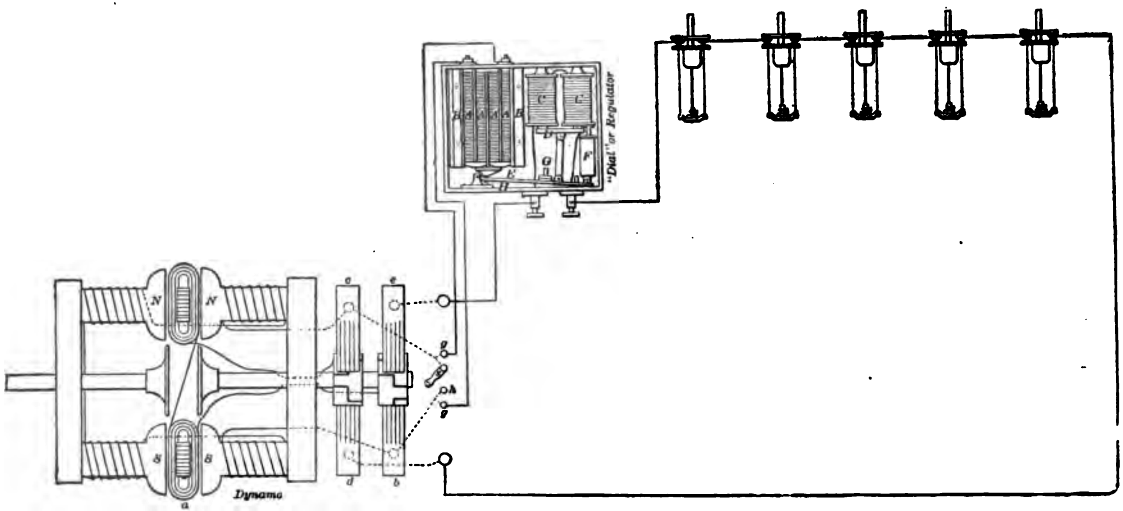


Fig. 33.—Brush System of Current Regulation.

coils are connected together, while the outer ends lead to the commutator segments through a portion of the shaft which is hollowed out for that purpose. The connection between the ends of the armature wires and the commutator wires are made by "butting" the ends in a copper sleeve and soldering the whole together. The commutator is shown in Fig. 24. A diagram of the field windings, brush connections, automatic current regulator, or "dial," as it is called, and the dynamo switch connections, are all shown in Fig. 33.

Referring to the diagram of the dynamo, you will notice that there are four pole pieces, two of *N* and two of *S* polarity, arranged as shown. The field coils are in series. The binding screws, *g g*, hold the wires leading to the dial. The switch *s*, when in contact with *h*, makes a short circuit across the field coils and cuts the dynamo out of action. We will trace the path of the current produced in the coil *a* through the armature wire to the commutator segment in contact with the brush *b*, through which it flows. From this brush, if the dial is not in action, the current passes to the field, around all the magnets to the brush *c*, thence through another set of armature coils, where the potential is increased, then out through brush *d* to the line and through the lamps and regulators to the brush *e*, thence completing the circuit through the armature.

The circuits and connections of this dynamo are among the hardest to trace and thoroughly understand, but when you have once mastered them you will find but little difficulty in tracing out and understanding the circuits of other systems.

A little explanation in connection with this diagram may serve to make several principles more clearly under-

stood, perhaps, than if treated separately. On starting the current, the dial, or regulator, is out of action, and the carbon piles are separated from all contact with the binding screws on the top of the box. This prevents any of the current from being short-circuited on the fields until the current on the line has reached the required amount. As each lamp requires current of 9 amperes and 45 volts, we will require a potential at the dynamo that will give 45 volts for each lamp in the circuit, and maintain a nine ampere current on the line.

As soon as the potential has become sufficient to give the required current, the dial is brought into action by the solenoids attracting the armature and raising the lever so that the carbon piles are brought into contact, and a portion of the current is short-circuited across the field, thus reducing the magnetism of the poles until it is just sufficient to maintain the current at that point. If a few lamps be cut out, thus reducing the resistance, the current will increase and the attraction of the solenoids, giving a stronger pull on the lever, presses the carbon pieces more closely together, reducing their resistance and allowing more current to pass through the short circuit across the fields. A very little change in the position of the brushes reduces the sparking which follows a lessening of the load.

Should more work be thrown on the line, the current will be lessened, the solenoids allow the lever to drop, the resistance through the shunt (or short circuit) around the fields is increased, and as a result, less current can flow across, consequently more must flow through the field coils, increasing the magnetism and producing more current on the line.

Closing the switch *S*, completely short circuits the field and stops the production of current in the dynamo, because the magnetizing current is cut off from the field coils.

THE DIAL, or regulator, consists of four piles of carbon pieces, *A*, *A*, *A*, *A* (Fig. 33), separated by strips of slate, and insulated from the iron box in which they are enclosed by sheets of slate, which is a very good insulator. These carbon pieces are about one inch square and of different thickness. The piles are connected in such a manner as to form one continuous conductor, of great resistance. The solenoids, *C*, *C*, through which the full current passes, attract the armature, *D*, which being connected to the lever, *E*, controls the current by pressing the carbon pieces more or less closely together, varying the resistance through which a portion of the current is short-circuited outside the field coils. The dash-pot, *F*, serves to ease the movement of the lever. Weights may be placed on the pin, *G*, to vary the amperes of current on the line. The carbon piles are covered with a sheet of slate, which is fastened to the sides *B*. The binding posts on top of the box make connection with the carbon piles, when the dial is in action. The wires leading from these binding posts connect to the field coils of the dynamo, as shown in the diagram.

The current used in the Brush system of 2,000 C. P., is about nine amperes, and the dial is weighted to regulate the current to that amount.

If the slate cover be removed from the dial, the carbon pieces are quite sure to fall out, and, if such an accident should happen, you will find it an exceedingly tedious operation to replace them and balance the dial again.

The following pointers may be of assistance to you, if you ever find it necessary to overhaul or readjust a dial. When the dial comes from the works it is all right and in the best of condition, and needs no further adjusting, but just fasten it to a solid wall or frame, in a level position, remove the wooden blocks that held the parts in position during the transportation, fill the dash-pot with a mixture of glycerine and alcohol—or water may be substituted for the alcohol. A mixture of glycerine and water will not freeze solid or become very stiff in cold weather. Connect the dial to the dynamo, as shown in the diagram, without any consideration for positive or negative wires, for it will work equally well either way, except when using the dial controller, which will be explained further on.

After continued use, the carbon pieces frequently become burned, so that it is necessary to replace them with new ones, or remove them and smooth them down. The contact pieces at the top sometimes become broken. If you find it necessary to overhaul the dial, it should be taken down and tipped partly on its back, in such a manner that it will not slip or fall. The carbon pieces should all be taken out, and those that are broken or burned should be laid aside and new ones supplied in their place. The pieces should be placed in their original position, having a thick piece at top and bottom of each pile, and thick pieces should be put in so there will be four thin pieces and then one thick one, then four thin and another thick one. Fill each of the spaces in this manner, placing a long thick piece on top of the two center spaces. The square pieces that are beveled on one side are placed at the bottom of each pile, and the longer ones of similar shape are placed under these last, supporting two of the smaller

ones. The insulated piece supports these, and rests on the adjusting screw, *H.* With the dash-pot removed, so you can work the lever easily, raise the lever until the carbon pieces are pressed firmly together, which should bring the armature, *D*, about one-fourth inch from the solenoids. The distance can be regulated by the adjusting screw. When the lever is down, the carbons should break contact at the top. The longer carbon pieces at the bottom should stand square. If they are tipped sideways, they may be squared up by changing some of the thinner pieces from one pile to another, until the piles are of equal length.

Overhauling a dial is a tedious job until you "get the knack of it." When the dial is in perfect condition, it will regulate the current for any number of lamps, from the full capacity of the dynamo down to one lamp. The less space between the armature and solenoids the greater the pull the solenoids have on the lever.

When lamps are switched off, the carbon piles usually become quite warm, but this is no occasion for alarm.

A small amount of kerosene poured on top of the glycerine mixture in the dash-pot will prevent the evaporation of the alcohol.

Never take off the slate cover, unless the dial is tipped back, for the carbon pieces are liable to fall out.

The dial controller shown in Fig. 34, is attached to the ordinary Brush dial as shown. The wire to the right in the dial, which should be the positive wire, is cut and connected to the controller at *a a* and a copper strip connects the controller to the other wire at *b* without cutting this wire. The carbon piles should have less resistance when using the dial controller than when working without, and the dash-pot *F* is made to work somewhat stiffer by

soldering the valve so that, practically, it becomes a solid piston. Thicker glycerine is also used in the dash-pot than is required when not using the dial controller.

The dial controller consists of an electro-magnet *J* made flat for convenience; the armature *K*, which is a conductor

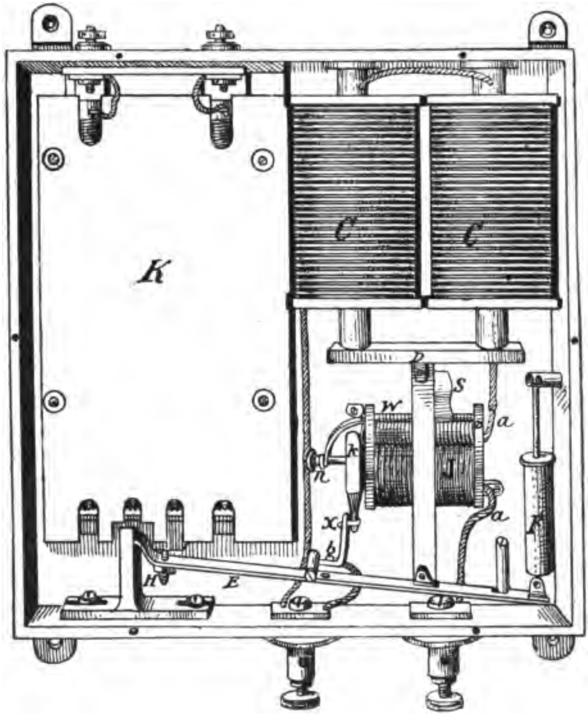


Fig. 34.—Dial Controller.

for a portion of the current shunted through the resistance *W*, which consists of two open coils of iron wire wound on an insulating material and lying parallel. The brass spring *S*, which opens between the two coils, forming a means of

regulating their resistance by cutting out of circuit more or less turns of the iron wire, and which will govern the amount of current passing through the shunt. The screw *N* is used to adjust the distance of the armature from the magnet; *K* is a slate cover to protect and keep in position the carbon piles which form the resistance of the shunt across the field coils. When running with a full load the dial is out of action, the lever *E* being down as far as it will go. If a portion of the load be thrown off by cutting out some of the lamps, the lever will raise, and the contact *x* should be open, but never more than 1/16″, and it is quite important to have this contact adjusted just right, so that the space between will be only sufficient to break the small arc that is formed there when the contacts are separated. The distance to which the contacts separate may be adjusted by the screw *N*. If the smaller contact is being eaten away by the spark, it may be stopped by changing over the wires in the large binding posts at the bottom of the regulator. This will change the direction of the current through the contact *x*, and cause all of the erosion to take place on the larger contact piece where it will not do any particular harm. When more work is thrown on the line the magnet *J* loses a portion of its magnetism and the armature *k* is drawn away by the spring and the contacts close. This allows a portion of the current to pass through the shunt *W*, lessening the strength of the solenoids and allowing the lever to move downward, which lessens the resistance of the shunt around the field, allowing the current to increase. If the lever does not drop when the contact *x* is closed it will be found that the resistance *w* is too high. This may be regulated by moving the spring *s* to the right, which will lessen the resistance of

the shunt, allowing more current to pass through that way and less through the solenoids. It is always best to keep the spring *s* as far to the left as possible and yet have the regulator work all right, and when the spring has once been set in the correct position it will not require any changing, unless other parts of the regulator become considerably out of order, and even then it is better to put the other parts in order instead of changing the spring. If a large spark appears between the contacts *x*, it will be found that the resistance of the shunt *W* is too low, allowing more current than is necessary to pass through the shunt. When this is the case, the contacts will be destroyed in a very short time or will become so badly corroded that the sensitiveness of the regulator will be greatly impaired.

If it becomes necessary to put more current on the line than the regulator is adjusted to, it may be increased to any extent within the capacity of the dynamo by turning the fibre nut *N* to the right. But you will understand that the dial does not produce current, it only regulates it, and if the lever *E* is down, the full current that the dynamo will produce at that speed, is then on the line, and no amount of adjusting the dial will increase it.

If too much current is on the line, turn the nut slightly to the left.

At all times when the dial is in action, there should be sparking at the contacts of the controller.

The armature *D* should never be allowed to rise high enough to touch the solenoids. This is adjusted by the screw *H*, which, if turned to the right, pulls the armature away from the solenoids.

Fig. 35 shows the field and brush connections of a sixty-five light Brush dynamo, which is introduced for the benefit of those having charge of such machines, who wish to understand the path of the current. It is also an excellent diagram from which young electricians may test their knowledge of the action of the current by tracing the circuit.

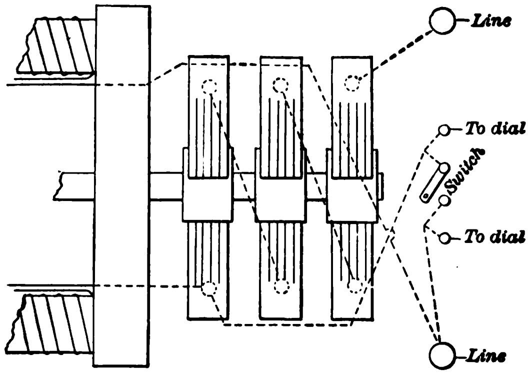


Fig. 35.—Connections of a No. 8 Brush Dynamo.

The field coils (not shown) are connected up in the same manner as shown in Fig. 33.

This dynamo has twelve coils in the armature. The commutator is divided into three sections of four segments each. Six brushes are required.

BRUSH INCANDESCENT, COMPOUND WOUND, SELF-REGULATING DYNAMO.

The accompanying diagram shows the field circuit and brush connections of a compound wound dynamo for incandescent lighting, which is self-regulating. The binding posts are shown at *A*, *A*, and the brushes make connections at *b*, *b*, *b*, *b*.

It will be noticed that the portion of the magnets nearest the pole pieces are wound with large wires (number one), and are connected in a peculiar manner, two being in multiple from one of the brushes, and the opposite magnets in multiple from the other brush on the same side, but the exciting portion of the circuits, you will notice, are in series between the brushes and the line. This part of the winding might be described by the expres-

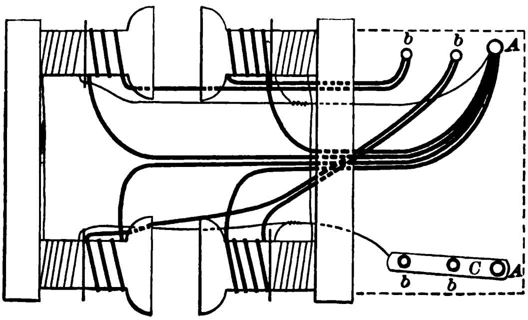


Fig. 36.—Connections of Compound Wound, Automatic Regulating Dynamo.

sion "multiple-series," for they are in both multiple and series. The smaller wire is wound on the other portion of the magnet, and separated from the larger wire by a thick washer of vulcanized fibre, which effectually insulates it from the exciting wires. This small wire is in "shunt" between the binding posts, and the current passes around the magnets in the same direction as it does in the coarse wire circuit.

The fine wire coils contain a very great length of wire, and make many turns around the magnet. As this shunt circuit is of very high resistance, only a small amount of

current can pass through, and as the resistance on the line is reduced by the addition of more lamps, less current passes through the shunt coils and more through the main coils; consequently the pole pieces are more strongly energized and more current is delivered to the line. But should a part of the lamps be turned off, the resistance on the line is increased and more current passes through the shunt, but less through the series winding, demagnetizing the pole pieces in proportion to the decrease in the amount of current passing through the field coils. A small amount of current passing through a great number of turns of wire has as much magnetizing effect as more current passing through a less number of turns. The exact proportional effect depends on several factors, and requires more or less calculation and some experimental tests. The commutator in use on this dynamo is of the style shown in Fig. 24, and the brushes, as shown at *a* Fig. 25, about three inches wide, a wide brush of this kind being necessary to carry the large number of amperes of current generated by this machine. The armature is of the same style as is used in the other Brush dynamos.

CHAPTER XI.

AUTOMATIC CURRENT REGULATOR AND OTHER APPLIANCES OF THE EDISON SYSTEM OF INCANDESCENT LIGHTING.

The automatic current regulator of the Edison system is shown in perspective, in Fig. 37.

The box contains the resistance, which is German-silver wire of small guage, wound on reels and the turns insulated from each other by an air space. From this wire, loops are taken off at intervals, which are connected to the strips marked *r*, *r*, *r*, in the figure. These strips are all brought together to form a commutator at *R*. In the commutator, the strips are separated by mica or fibre insulation, which is necessary, of course, though these strips are all in contact with the same mass of wire at one end; similar to the connections of the rheostat shown in Fig. 29.

This is in reality a rheostat but of somewhat different form. The controller magnet marked *GG*, is an ordinary electro-magnet, the armature of which is connected to an arm, one end of which is pivoted to the frame that carries the controller magnets. The other end of the arm is extended upward and passes through a slot in a small table. This slot allows the arm sufficient play and also prevents the arm from making contact with the table; but on the table are two contact points, shown at *i i* in the diagram Fig. 38. These contact points are insulated from

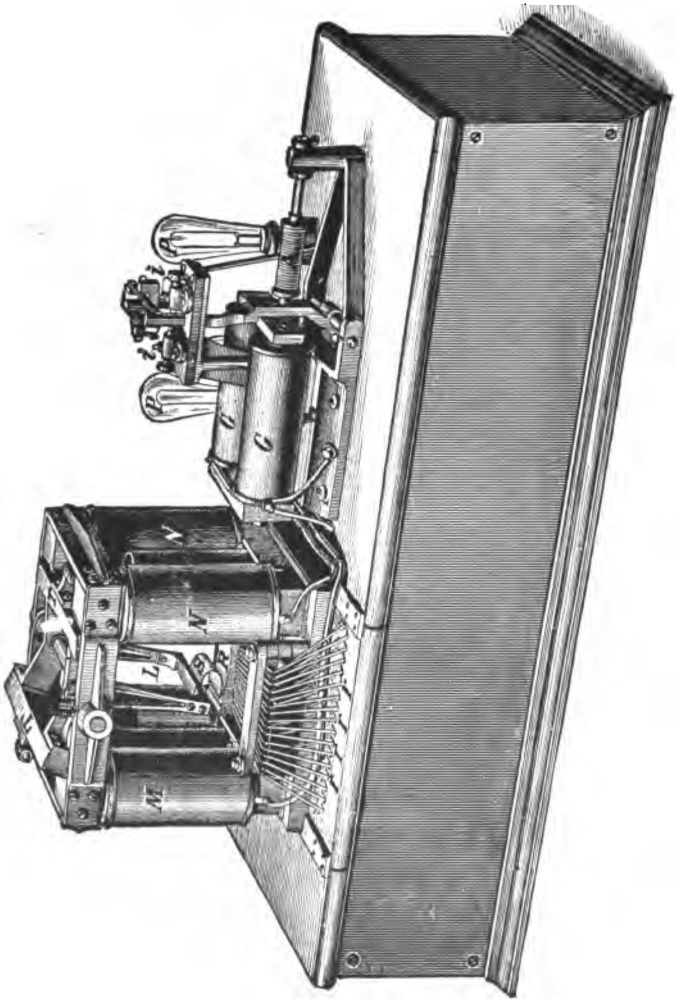


Fig. 37.

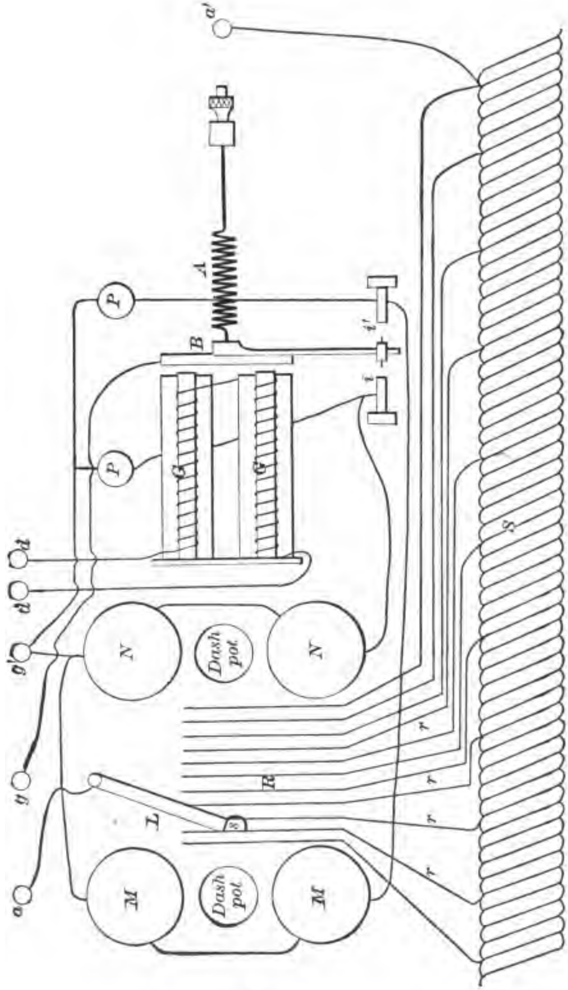


Fig. 38.

the table but wires leading from them form parts of the circuits as shown in the diagram. Above these contact points are two flat springs against which the end of the arm works. These springs receive the blow of the arm which would otherwise batter the contact points. The springs are no part of the circuit.

A retractile spring *A* is connected to the arm at about the same position as the armature is attached. This spring is for the purpose of regulating the potential at which the regulator shall act.

The incandescent lamps marked *P P*, are not placed there for the purpose of giving light but are used as a resistance. The lamps are not connected in the circuit direct but are in the shunt or derived circuit with the contact points *i i* as shown in the diagram.

The use of the lamps in this position are for the purpose of receiving the extra current that is formed when the contacts separate and the circuit through the motor-magnets *M M* or *N N*, is broken. The motor-magnets and the double armature *T T* are for the purpose of working the lever *L*, that carries a brush or spring at its end. The brush moves over the commutator, making contact with the strips leading to the resistance.

This lever and brush forms part of a circuit and carries the current that passes through the field circuit of the dynamo. On the regulator are six binding posts, not shown in the cut, but represented on the diagram at *a a′ g g′ d d′*. These serve to connect the regulator to the different portions of the circuit as is necessary for its proper action.

The binding posts marked *a a′* are the terminals of the circuit through the resistance *S*, and are connected in

series to the field circuit of the dynamo. The frame carrying the motor magnets forms a part of this circuit and the coiled wire shown on top of the frame is to insure good contact between the frame and the shaft of the double armature. The lever *L*, is connected to this shaft.

A good reliable contact cannot be made between a shaft and its bearings, on account of the lubricant used, and the shaft working loosely in the boxes, that is as satisfactory as when something like the coiled wire here shown is employed.

The spring *s*, insures good contact with the commutator *R*, and it is not necessary that anything in the way of lubrication should ever be used on this commutator for it never gets to sparking or cutting as some dynamo commutators do. Placed between each pair of motor magnets is a dash-pot, the piston of which is connected, by the rod, to the armature *T*.

There is one of these dash-pots connected to each side of the double armature and the cylinder is filled with cylinder oil, in some cases, or with glycerine. The use of the dash-pot, in this case, is for the purpose of steadying the movement of the lever *L*, which would be thrown too far across the commutator at each slight change in the current on the line, if some means were not provided to make the movement of the lever slow and steady.

Keeping these dash-pots in good working order is just as necessary to the successful working of the regulator and consequently to the satisfactory operation of the whole system, as any other detail about the plant. In fact it is necessary to pay particular attention to all the different details about a plant of any kind in order to get good,

smooth, continuous work out of it. If the glycerine or oil in the dash-pots is too thick then the lever would move too slow and when any great number of lights were turned off the other lamps would brighten up and continue so until the pull on the armature had continued long enough to overcome the resistance of the thick oil or glycerine and, what is worse, long enough for a person to notice the brightening of the lamps and their dimming down again which is sure to cause dissatisfaction. Or, if the movement is too free then the movement of the lever would be so sudden that the momentum of the armature would carry the lever too far across the commutator, throwing in too much resistance, which will have the effect of making all the lamps fall below the normal candle power and then suddenly brighten up again as the current is changed to the other set of magnets and the lever is pulled back again.

When the dash-pots work as freely as they should, any change in the number of the lamps can be made without producing any apparent effect on the others.

When the regulator is in good working order, the two lamps attached to it will be continually lighting up and going out; that is first one and then the other will brighten up as they are thrown into circuit, or the current through the motor magnets is broken. But they should not brighten up to full candle power at any time, but just become fairly red. If either should become fully bright unless when the dynamo is overloaded, it may be taken as an indication that the regulator is not working freely, and an examination of all the parts and connections will show where the difficulty lies.

The controller magnet circuit is, or should be, connected to the mains at *the center of distribution.* The

terminals at the binding posts, *d d*, is where the connections are made.

The reason for making connections between the center of distribution and the controller magnets is that if there should be any fall in potential on the mains, as there always is, that the average potential throughout the system may govern the regulation.

Wire of any size, no matter how large, offers more or less resistance to the passage of the current, consequently there will be less pressure at a distance than at the dynamo, and to equalize the pressure as far as possible throughout the system, is why the connection is made to the center of distribution.

The circuits of the motor magnets *MM* and *NN*, as shown in the diagram, are connected with the feeders at any convenient position. The two magnets *MM* are in one circuit and *NN* are in another circuit, but on one side of the magnets one terminal serves for both. The other terminal, *g*, connects to the arm that carries the armature *B*, and the circuit is completed through *MM* or *NN*, according to the action of the current on the controller magnet. By referring to the diagram you will notice how this is accomplished and also see the manner in which the lamps are connected in shunt to the circuits of the motor magnets. When a current of electricity is passed through a coil of wire, such as the circuit of an electro magnet, there is self induction between the wires; that is, the current passing through each turn induces a current in the turns of wire near it. The induced current is always in a direction opposite to that of the inducing current, and acts as a resistance to the flow of the inducing current.

When the current is broken this induced current is shown to a greater extent by a spark at the point where the break is made. A still greater and more destructive current is also formed when the circuit of an electro-magnet is broken, by the effect of the demagnetizing of the core which generates current. This is called the extra current. Any change in the strength of a magnet will induce a current in the wire that is near it. Under these conditions, the demagnetizing of the core will produce a current in the wire fully as strong as the sudden magnetizing of the core would produce but in the opposite direction, and this current together with that resulting from the self-induction of the coil gives a spark that is quite destructive to whatever may form the termination of the circuit at the point of breakage.

Under these conditions, in the regulator, the contacts *i i'* would soon be destroyed if some means were not provided to break the effect of this extra current that is formed each time that the circuit is broken at this point. The incandescent lamps are the means provided here to reduce this destructive effect by providing a path for the extra current through a resistance where the current expends itself in heating the filament, and by this means the contacts are preserved.

In connecting the resistance of the regulator to the dynamo the connection is made between the binding posts marked *a a'*, on the regulator, to the binding screws shown at *a a* on the diagram of the dynamo windings, Fig. 39.

This diagram of the winding of an Edison dynamo represents but one plan of winding in use on these machines; but as this style is, I believe, the most common and as it is sufficient to convey the ideas intended to be described it will be all that is necessary.

By reference to the diagram it will be noticed that the binding screws *a a*, are the ends of a break in the field circuit. The regulator is connected to these terminals. The dynamo is shunt wound. The pilot lamp is con-

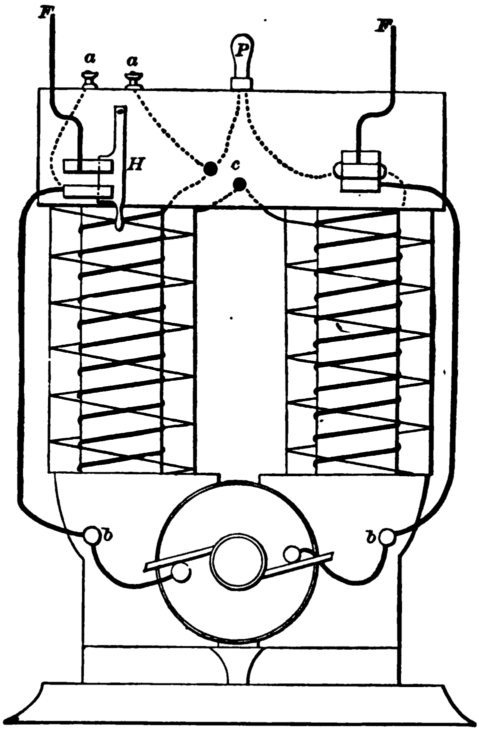


Fig. 39.

nected on one side to the feeder from the brush, while on the other side it is connected to the field coils. A close examination will show that the lamp is in reality connected in parallel or shunt to the field coils.

The button *c*, to which a loop in the field coils is attached, may also be used as a place where the regulator may be introduced into the circuit. This loop is usually brought up on the back side of the dynamo. All wires shown by dotted lines, in the diagram, are covered by the head board on the dynamo. The circles marked *bb* show the points at which the fuses are placed. These fuses are of sufficient capacity to carry the full current at which the dynamo is rated and will always do it if the contacts are kept in good order and not allowed to corrode. This will seldom occur if the fuse has been tightly clamped in its place, at the start and has not been interfered with afterward. Should a short circuit on the line occur, one or both of these fuses would immediately melt unless some other fuse on the line, nearer to the short circuit, first gave way. These fuses seldom melt out unless the dynamo is loaded up to its full capacity. An over-load is sure to cause them to melt.

Fuses should never be replaced with any metal but tin and it should not be any heavier than the fuse that was destroyed. The fuse is supposed to protect the dynamo from injury by over-pressure and is, in reality, to the dynamo what the safety-valve is to a steam-boiler. Cases have been known where fuses have been replaced by copper strips, but this is wrong and should not be done, for serious consequences are liable to follow.

The pilot lamp, if not kept screwed down tight may cause a trouble by melting the soldered connection to the lamp socket. This has occurred on account of the resistance ot a loose connection and the development of heat, as a consequence, which has been sufficient to melt the solder. Loose connections should never be allowed to exist in any

part of any electric circuit. Loose and corroded contacts are always a source of trouble and annoyance and the greater part of the mysterious difficulties in electric light plants may be traced to loose connections and corrosion of contacts.

The green and brown oxides that form on copper and brass when exposed to the air, especially moist air, are non-conductors of electricity and even a very thin film of this oxide has sufficient resistance to interfere with the successful working of a plant.

The less the potential on the circuit, the greater detriment will these small causes be It must not be understood that small, loose or corroded contacts may be neglected on systems of high potential, for even there they make very much trouble and are the more easily overlooked because many people are liable to infer that they cannot produce much harm because they still carry the current. This view is entirely wrong. Good practice requires that the conductivity of circuits shall be as near perfect as is consistent with other principles involved. Excuse the digression from the description of Edison machinery to a few remarks on the care of circuits, and we will return to the subject and describe the action of the regulator.

The dynamo being started and the resistance all thrown into the field circuit, the retractile spring *A* would hold the contact point at the upper end of the arm in contact with the screw *i′*, which would cause the current to pass through the motor magnets *M M.* The current would build up slowly so long as so much resistance was in the field circuit; but when the current became of sufficient strength to cause the magnets to attract the armature *T*,

its movement would cut out some of the resistance, by moving the piece *s*, in contact with a portion of the armature that connects to a point of less resistance in the box.

More current would then be allowed to flow through the field circuit and the lamps would be quickly raised to the full candle power. As soon as the required potential was obtained on the circuit, the regulator magnets *G G* would be thrown into action and the circuit through *M M* broken. Now is the time that the lamp *P* in this circuit becomes useful. As soon as the flow of the current through *M M* ceases the reaction takes place and the extra current returns on this circuit, and if no other means were provided to consume its energy a large spark would jump across the interval between the contacts just separated; but as this lamp is in a shunt around the magnets, the extra current is provided with an easier path than across an air space, and expends itself in overcoming the resistance of the lamp. As soon as the circuit through *M M* is broken, contact is made at the other point and the flow is through *N N*, until the brush travels across the commutator *R* far enough to cut in more resistance and lower the potential a trifle, when the spring *A* withdraws the armature *B*, breaking the circuit through *N N*. The other lamp then receives the extra current from these magnets. The changing of the path of the current from the magnets *M M* to *N N* is incessant, but the movement of the contact *D* is a mere trifle, except when the number of lamps in use is changed, and then the movement is not considerable, for a very small change in the resistance of the field circuit is sufficient to compensate for ordinary changes in the number of lamps.

THE HOWELL PRESSURE INDICATOR,

a front view of which is shown in Fig. 40, and a diagram of the connections and other portions of its interior is shown in Fig. 41.

The use of this instrument is to show when the current on the line is at the right potential. It does not, in any

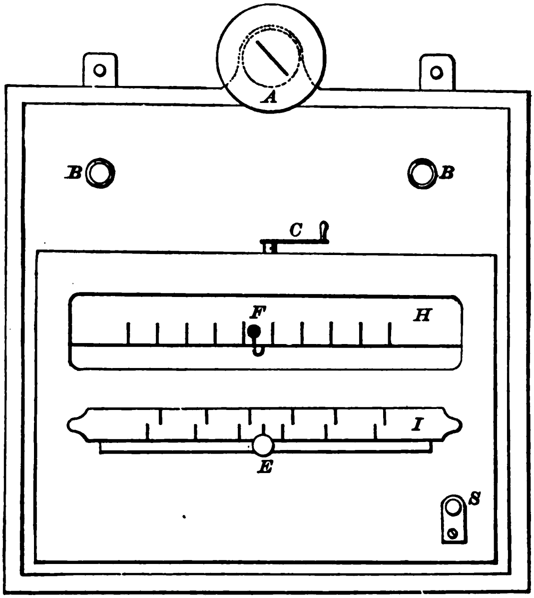


Fig. 40.—Front View Howell Indicator.

way modify the potential of the current or the brilliancy of the lamps, but merely shows if the potential remains at the required pressure, and indicates any change of potential that may take place on the circuit. The principal parts of the indicator, as shown in the front view, are an incandescent lamp marked *A*, the binding posts *BB*,

the small lever *C*, placed on top of the box that projects to the front, the scale *H*, the small black ball *F*, at the end of a wire that projects from the inside of the apparatus. This scale is covered by a glass that protects the interior from being tampered with, or the little ball from being assisted in its duties by the aid of sticks or a piece of wire. It is strange that it is sometimes thought necessary to assist indicators in their duties. We have frequently seen engineers tapping a steam gauge with their fingers or knife, apparently trying to make it register more than it was intended to do under the conditions. Electrical apparatus, if not protected from such usage, have shared the same fate. No amount of rapping or jarring an indicator will make the lights burn any brighter, no more than tapping a steam gauge will make an engine do more work.

Below the scale *H* is another scale *I*, whose graduations are marked with numbers. On some of these instruments are two sets of numbers, one in red ink and the other in black. Below this scale is a knob that can be moved the length of the scale. The knob carries a small pointer that can be set to any division of either set of figures on the scale. Near the right hand lower corner is a screw marked *S*.

Referring to the diagram, Fig. 41, for an explanation, we find a galvanometer, surrounded by an iron ring, shown by the heavy black circle. The galvanometer consists of a polarized piece of steel called the needle, balanced and working on pivots. The needle is pivoted inside of a brass frame, around which insulated wire is wound. When a current is passed through the wire, the needle tends to assume a position at right angles to the length of the wire. The position at right angles is only attained

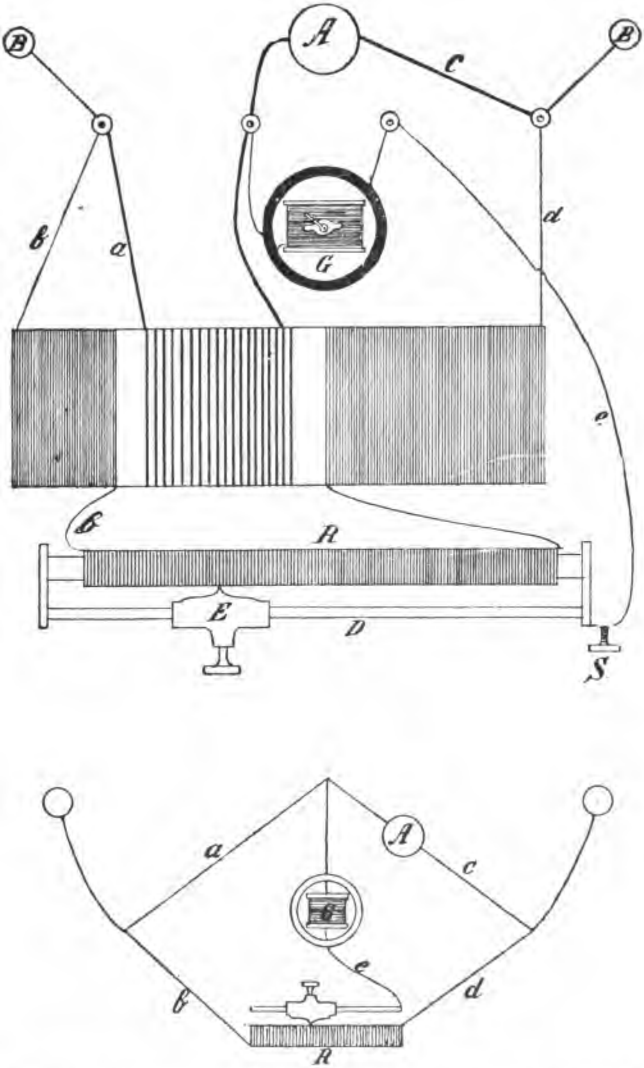


Fig. 41.—Diagram of Circuits of Howell Pressure Regulator.

when the strength of the current is very great compared to the magnetism of the needle, which must be small so that it may be easily moved, and be strongly affected by the current passing along the wires. A galvanometer may be made by wrapping a few turns of wire around a strip of pasteboard or a piece of cigar box, or in fact anything that will serve to wind the wire on. It is preferable that the wire be made into a flat roll. A common pocket compass is placed on the wire in such a position that the magnetized needle may point in the same direction that the wire is wound. When a current of electricity is passed through the wire the needle will move and tend to take up a position at right angles to the wire. This is the simplest form of galvanometer. But to make it more sensitive, the wire is wound above and below the needle. In the galvanometer shown in the diagram, the needle is placed between the wires. The part marked *P* is a piece of magnetized steel, and is connected to the small lever as shown. This is for the purpose of regulating the position of the needle.

The iron ring that surrounds the galvanometer is a magnetic shield for the purpose of protecting the galvanometer needle against the influence of outside magnetism. It serves the purpose very well. A great deal might be written about an iron ring when used as a shield against magnetism, but the statement of the fact is sufficient here. A few experiments will teach considerable in regard to it.

The arrangement of circuits in this indicator form an electrical balance and are arranged as shown in the lower portion of the cut. The letters refer to the same circuits in both places. The lamp, *A*, whose resistance varies with

its temperature, provides a delicate means of indicating any change of potential on the circuit. Any change in the potential will change the amount of current flowing through the lamp. This will change the temperature and resistance because carbon, when at a white heat or in a state of incandescence has but half as much resistance as when cold. The coil of wire *R*, which is of German silver and insulated, is for adjusting the balance to agree with the resistance of the different indicator lamps. The principles of the electric balance are fully explained in the latter part of this book, under the heading of The Wheatstone Bridge, but in this explanation of the indicator we will say that when the current on the mains is at the right potential there will be no current through the galvanometer *G*, and the needle, held in position by the small magnet *P* will keep the pointer at the zero of the scale.

The screw *S* forms a portion of the circuit, and serves to break the circuit at this point when testing the indicator. The indicator is connected in multiple to the mains near the center of distribution, for the same reasons that the controller magnet of the regulator is connected at that point.

The lamp is a special indicator lamp, and is of different resistance from the lamps used on the lines. Two special indicator lamps are usually furnished with each indicator, and one has a number on it in red ink, the other is numbered with black ink, and these numbers correspond with numbers on the Scale I, in the same colored ink.

These lamps and the indicator are tested and marked at the factory. The binding posts *B B*, serve to connect the indicator to the circuit. When no current is on the line, the little ball *F* should stand at the zero of the scale;

but as the potential rises it moves toward the side, but returns again to stand exactly over the centre line, when the current has reached the required potential. This it will do if the pointer on the knob *E* is set at the same number as is found on the lamp in the same colored ink. Should the potential increase, more current will flow through the indicator and the carbon in the lamp will become more highly heated, and its resistance becoming less a greater portion of the current can pass through the lamp, and this by destroying the balance between the two branches will cause some of the current to flow through the galvanometer circuit, and the pointer will be deflected.

Should the potential fall less current would flow through the indicator and the resistance of the lamp increasing disturbs the balance of the circuits and current flows through the galvanometer, but in a direction opposite to what it does when the balance is disturbed by an increase of potential. The potential is kept at the required amount by regulating with the resistance box in the field circuit.

The indicator may be tested at any time when the plant is running, by opening the circuit at the screw *S*—which merely breaks the galvanometer circuit. If the indicator is all right, the pointer will stand at the center. If it does not stand at zero, it may be adjusted so that it will, by moving the lever *C*, but this lever should never be moved unless the circuit is open at the screw *S*. One of the indicator lamps should be kept for the purpose of testing the other by.

After a lamp has been attached to the indicator, for a length of time, it sometimes occurs that its resistance has become changed, more or less; this may be tested at any

time by placing the other indicator lamp in the socket, and setting the pointer on the scale at the number found on the lamp. The indicator should then mark the same as before. If it does not mark the same, bring the pointer to the zero point on the scale by regulating at the rheostat, and then replace the first lamp and bring the pointer to the zero mark, by moving the knob *E* until the pointer rests at zero.

It is well to keep two indicator lamps on hand at all times, using one on the indicator and retaining the other to test by occasionally. The lamp that is kept for testing may be presumed to be correct at all times, if not used for other purposes. The lamp used in the indicator sockets will last for an indefinite length of time if it is not accidentally destroyed, for the amount of current through the lamp is so small that the lamp never burns at more than one-half its candle power, and at that rate the lamp should last for years.

CHAPTER XII.

THE EXCELSIOR SYSTEM OF CURRENT REGULATION.

The dynamo of this system is of the ironclad type. The field magnets are placed in a vertical position, and are wound in sections, or rather loops are brought out at intervals and connected as shown on the left in Fig. 42. The armature is peculiar to this machine.

The current regulation is obtained by the moving of the brushes, together with a device that cuts out or in a greater or less number of turns of wire in the field-coils. Both these results are produced by a motor placed on the side of the dynamo, and actuated by the current. The different circuits and connections, together with the motor and the short circuiting switch, are shown in the diagram. The winding of the field-coils is not exactly as shown in the diagram, but the method by which the regulation is obtained can be easily understood from the plan shown.

The coils of the field-magnets are each divided into two parts by a washer of vulcanite, placed about midway of the length of the core. The wire is wound in such a manner that branches are brought out at intervals and connected to small brass plates, of which there are two sets, as shown at *B*, on the left of the diagram.

Each branch that is brought out represents a certain amount of wire in the field-coils. The terminals from

each section of the coils are connected to plates opposite the terminal of a corresponding section of the other field-coil. The bar *S* carries on its under side a double brush, insulated from the bar, that presses on the plates and

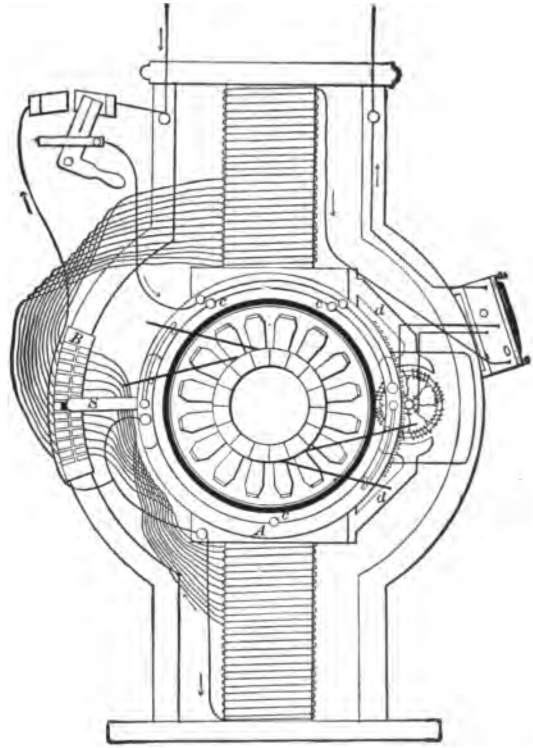


Fig. 42.—Excelsior Dynamo and Regulating Apparatus.

serves as a conductor between them. This brush, not shown in the diagram, carries the full current. This brush should always have sufficient contact to carry the current without heating and without causing any spark as

it passes from one plate to another. It should also be kept tightly screwed up. Loose contacts in any part of an electric circuit can always be relied on to produce trouble.

The armature core of this machine is built up of numerous iron ribs, one end of which fits into holes drilled in bars that run lengthwise of the shaft, and are fastened to rings that form a portion of the frame work. The other end of the ribs are held in place by a cap piece that is fastened by screws.

The armature coils are wound separately on a mandrel, and are of a form similar to a link, and of square section. These coils encircle the ribs of the core, by which they are held in place, and are connected up in close circuit. The principle of this armature is that of a gramme ring, but its construction is such that any of the coils can be easily removed at any time, and replaced with others if necessary. The loosening of a couple of bolts admits of this.

The commutator is composed of 16 segments, having quite heavy projections at one end which stand off at a right angle and are attached to a disc of slate which is rigidly secured to the shaft. This slate disc is about $\frac{7}{8}''$ thick and is the only insulation except the air space about the commutator. The armature wires are connected to the commutator by a clamp at the end of the projections. The brushes are four in number, two on each side, and each pair are placed side by side, and one about an inch behind the other, or far enough apart so that one is sure to make good contact while the other is passing the space. The leading brushes run with a small spark, while the others should carry no spark at all.

Double brushes and the necessity for them is shown and explained under Fig. 26, in a previous chapter.

The brush holders are attached to, but insulated from, a metal ring, *A*, that is carried on small flanged rollers *c c c*, that allow it to rotate freely while still holding it in place. These rollers should always be kept working free, for if allowed to stick it will cause an unnecessary amount of resistance to the free movement of the ring, and an unsteady light will be the result. A portion of the ring *A* has attached to it a rack that engages with a pinion on the end of the shaft of the small motor enclosed in a box, and shown at the right of the diagram. The pole pieces of this motor are projections from the pole pieces of the dynamo as shown at *d d*. The brushes of the motor are placed vertically, and are connected in shunt to carbon resistances in the regulator box shown on the right. A sketch of the inside of the box is given in Fig. 43, where *M M* is an electro magnet, and *H* and *K* are carbon rods. *F* is a brass piece that serves as a conductor and to hold one end of the carbon rods *H* and *K*. One wire leading to the motor is also attached to this piece at *G*, while the other wire to the motor is connected to the piece marked *J*. The strip *Q* that carries the armature *N*, is made of rolled copper or phosphor bronze, and works between the adjusting screws *O P*, and is clamped to the block *J*. The tension spring *q* serves to regulate the intensity of current at which the regulator shall act. The tension of this spring is adjusted by the screw *R*, which presses against the end of the lever where it is hinged to the box. By the tension of this spring the current on the line may be carried at any number of amperes desired, within the capacity of the dynamo. The strip *S* is a short circuit between the main-circuit wires *1* and *2*, where the current enters and leaves the box.

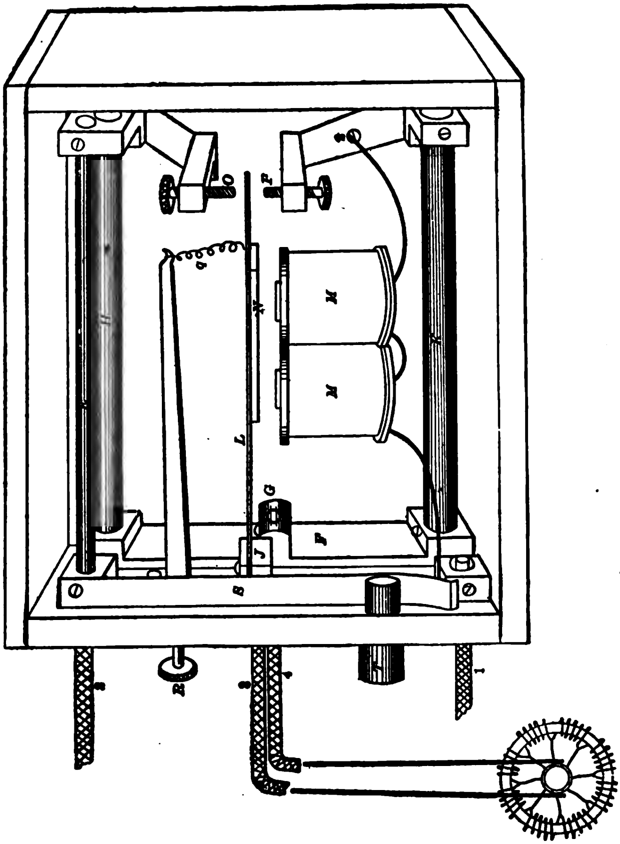


Fig. 43.

This short circuit is operated by the switch *T*, which projects outside of the box.

The current enters the box by the wire *1*, which is connected to the square brass piece that also serves as a terminal for one end of the magnet coils. The other end is connected to the conducting strip at the screw *v*; from here, if the current be too weak for the magnet to attract the armature against the pull of the spring *q*, the path will be through the strip and carbon rod *K*, which has a certain resistance that is sufficient to shunt enough current to work the motor when the conditions are right. The current then passes on through the piece *F* and the carbon rod *H*, which also has a certain resistance, to the brass piece that holds the end of the rod and one end of the copper wire *E*, through which the current then passes to the line on the wire *2*. The wires marked *E* and *2* are both fastened to the same piece in the left hand upper corner of the box. This wire marked *2* leads from the box to a binding post on the dynamo, as shown in Fig. 42. The two wires marked *3* and *4*, leading to the motor, are connected, respectively, to the pieces shown at *J* and *G*. The short circuiting strip marked *S* is fastened at one end to the block where the wire *2* terminates, and the other end is close to, but not in contact with, the block where the wire *1* ends; but the switch *T*, when turned, throws the end in contact with the block, and thereby short-circuits the current between the ends of the wires *1* and *2*, thus allowing any changes or adjustments to be made to any portion of the contents of the box.

At the upper part of the dynamo, on the left hand side is placed a short circuiting switch. This is shown detached for convenience of illustrating in the diagram, Fig. 42.

Usually on these machines the upper brush is the positive, and by tracing the conductors from the brushes you will easily see the path of the current. Starting from the upper brush the current passes to the lower field magnet and through as much of the field coil as is in circuit (about one-half, as shown in the diagram) to the brush on the under side of the strip *S*, which is fastened to the ring that carries the brush holders and moves with it, and this brush makes contact with the terminal of a portion of the upper field coil that corresponds in number of turns to that portion of the lower field coil which is in action. This arrangement produces an equal strength of field in each pole piece, and also provides a means of varying the strength of the field, as required, by simultaneously cutting in or out an equal number of turns of wire in both field coils. From the upper coil the current passes to the regulator box, where it enters by the wire shown at *1*.

After passing through the box it leaves by the wire *2* at the top, and passes to the line by way of the binding post shown near the top of the frame, on the right hand side of the dynamo. Returning by the binding post on the left hand side of the machine and through the short-circuiting switch (Fig. 42)—which is shown set to the line—and passing on reaches the lower brushes. When the switch is thrown to the other contact piece the lamp circuit is opened, and also the circuit through the field coils, but this action also produces a short circuit between the brushes which causes the current—from want of support in the fields to quietly die away.

To clearly explain the action of the regulator, we will suppose that upon starting the dynamo the switch is in contact with the left hand plate, the brushes are in position

of greatest action, that is, as for back as they will come; the piece *S* over the lower strips connecting to the branches from the field-coils, which brings the whole number of turns of the field coils in circuit.

The lever *L*, Fig. 43, will be in contact with the adjusting screw *O*, held there by the spring *q*. When the dynamo is up to speed the short-circuiting switch is changed to the other contact, which will include the field and lamp circuit, the magnets are energised, and the current soon reaches the required strength with the lamps all burning. Should the dynamo not be overloaded, the regulator magnets *M M* will attract the armature *N*, drawing it down until the end of the lever *L* makes contact with the adjusting screw *P*. Then the path of the current through the box will be: through the magnet *M M* to the screw *v* where contact is made with the strip that forms the conductor between the screw *P*, and the piece that holds one end of the carbon rod *K*. From here there are two paths for the current, one through the carbon rod *K*, and the other by way of the screw *P*, the lever *L*, and the wire *3*, to the motor, through the armature of the motor, and by the wire *4* to the connection at *G*, on through *H* and *E*, out to the lamp circuit. As there are two paths for the current from the point *v*, the amount of current flowing through each path will be inversely as the resistance of each path, that is, the greater portion of the current will pass where there is the least resistance.

The resistance of the carbon rod *K* is great enough to cause a portion of the current, sufficient to work the motor, to pass through the wire *3* and back to the circuit through the wire *4*. This will cause the motor to revolve to the left, and the pinion on the end of the shaft engaging

with the toothed rack on the rim of the ring *A* will cause the ring to revolve to the right, and the contacts on the end of the piece *S* will move over the strips, cutting out sections of the field coils, and reducing the strength of the field. This will lower the potential of the current, and the movement of the ring will at the same time bring the brushes into position of lesser action, and the current being reduced, the Magnet *M M* will lose a portion of its strength; the spring *q* will then pull the lever *L* out of contact with the screw *P*. More lamps being cut into circuit has the effect of reducing the amperes of current on the line, on account of having increased the resistance, and to bring the current up to the required amount, the potential must be increased. An increase of magnetism in the fields will produce an increase of potential.

When the current has fallen below the required amount, and the magnet *M M*, consequently, has lost a portion of its strength, the spring *q* will pull the lever into contact with the screw *O*, when a portion of the current will then be shunted through the armature of the motor in the opposite direction. By referring again to Fig. 43 you will notice that when the lever *L* is in contact with the screw *O* on account of the current having fallen below the required strength, the path of the current will then be through the magnet *M M* to *v*, as before, but from here the whole current, instead of a portion of it, as before, passes through the carbon rod *K* and the piece *F*, until meeting the resistance of the other carbon rod *H*, a portion of the current is shunted through the wire *4*, from its contact at *G*, and passing through the armature returns by the wire *3*, and through the connection in the block *J* to the lever *L*, and through that and the screw *O* and connecting strip

to the block that holds one end of the carbon rod *H* and the wire *E*, and by the wire *E* to the lamp circuit by way of the wire *2*. From the explanation given and by tracing the circuits you will readily understand that the direction of the current through the motor depends on whether the lever *L* is in contact with the screw *O*, or the screw *P*, bringing the motor in shunt with one or the other of the carbon rods which, on account of their resistance, shunts, or as you might say forces a small amount of current to pass through the armature of the motor. The pole pieces of the motor remain of the same polarity at all times, and by this means enable the direction of revolution of the armature to be changed as often as the direction of the current through the armature alone is changed; but if the field magnets of the motor were in circuit with and charged by the same current that passes through the armature, a different result would be obtained, for by passing a current through both armature and field-coils of a motor in either direction the resulting motion will be the same in either case. To reverse a motor it is necessary to change the direction of the current through either the armature or the field; but not both at the same time.

By changing the direction of the current through the armature alone—allowing it to remain the same through the field—an opposite direction of revolution will result. Or by allowing the current to pass continuously through the armature in one direction and changing the direction through the fields, motion in either direction may be obtained. The extension of the pole pieces of the dynamo to provide pole pieces for the motor in this case was an excellent idea, for it has obviated the necessity for a field

circuit, and reduced the necessary mechanism to a minimum. The arrangement for changing the number of turns of wire in the field coils that are in action, at the same time as the position of the brushes are changed, and making them both dependent on and almost simultaneous with any change of resistance on the lamp circuit, must necessarily result in a very steady current and a satisfactory light. In the regulator box, attention should be given to the ends of the two springs *O* and *P*, and where they make contact with the lever *L*. The points become corroded after a time, and offer an unnecessary resistance which, by allowing considerable change in the current to take place before the regulator can act, will result in bad action in the lamps. Clean the contacts occasionally with a strip of sand-paper, so that they will make good contact when together, and by this means avoid one source of trouble. The same suggestion applies to all moveable contacts where electricity is used. *Keep the contact surfaces clean.*

Where the armature wires are connected to the commutator is a place that needs looking after occasionally. See that the connections are in good order, and all the screws firmly screwed down. If the wire in the armature heats more than usual it will be well to examine all of these contacts, and if no other reason is found for the armature heating, there will probably be one or more of these contacts found to be loose or corroded.

When everything about the dynamo and regulator is in good working order, and the dynamo not overloaded, the lever *L* should be constantly vibrating between the screws *O* and *P*. If this does not occur, or if its action should only take place at intervals of several minutes, it

will be on account of some portion of the regulating apparatus not working as freely as it should. Probably the ring A, or the rollers that support it, have too much friction for the required freedom of movement.

There are many points to which attention has been specially directed in these chapters that will apply universally to all kinds of electrical machinery. The chapter on commutators and brushes was designed to cover the requirements for all the different styles of continuous current dynamos and motors.

CHAPTER XIII.

THE SCHUYLER SYSTEM OF AUTOMATIC CURRENT REGULATION.

In the Schuyler system we find a series dynamo of the consequent pole type and a drum armature. A glance at the machine, as shown in Fig. 44, gives all of the outward characteristics in a clear way, four field coils with two fields. The frame is in halves, bolted together on a line

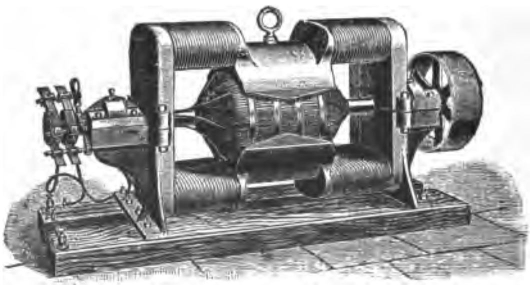


Fig. 44.—Schuyler Dynamo.

with the armature shaft, which makes it convenient and easy to remove or replace the armature. The removal of several bolts allows the upper field and half the frame to be lifted off and an eye-bolt conveniently placed in the upper field facilitates the operation. The armature shaft can then be easily removed.

The armature possesses peculiar features, as will be seen by referring to Fig. 45, where the method of winding

is so clearly shown. This particular armature contains four coils wound on a drum which is built up of sheet iron rings securely fastened to the shaft. The ends of the cylinder are open for the purpose of giving free ventilation, which is considered by some to be necessary to prevent a burn out from over heating while at work. Each coil is wound in such a manner that one-half the number of layers is on each side of the shaft. Each coil is also separated from the others by wooden strips placed between the coils and fastened to the drum. The means taken to keep the coils entirely free from each other ensures good

Fig. 45.—Schuyler Armature.

ventilation and promises a safeguard against burning out from overheating during a very long run. The collars on the shaft prevent end play, and by working in the journal box provide a method of self-lubrication that is an excellent feature, as a single filling of the oil cellars is sufficient to lubricate the journals for a full month's run without further supply.

The commutator is in two sections, each section divided into four segments, and the spaces between the segments filled by wooden strips to preserve a smooth surface for the contact of the brushes around the entire circumference of each section of commutator. By introducing wooden strips between the segments in this manner, dust and fine

particles of copper are prevented from gathering, which, if allowed to accumulate, might, in a short time, form a short circuit between the segments and result in a burnt out commutator or armature coil. Commutators somewhat similar to this have been destroyed because of an accumulation of dust having been allowed to gather between the segments. Attention should always be given to this point on any dynamo.

The armature is connected up in open circuit. The terminals of the coils are brought out through the shaft, a portion of which is made hollow for that purpose, and are connected to the segments of each section of commutator alternately, that is, the terminal of one coil is connected to a segment on the outer section and the terminal of the next coil is connected to a segment on the other section. By referring to the cut you will see that the segments of the two sections lap in such a way as to make their position correspond to the position of the coils on the armature. The brushes on these machines are usually of rolled copper, and though but four brushes are shown in the cut, which represents their latest style of dynamo, most of these machines use eight brushes.

With open circuit armatures double brushes are essential unless other means are provided to bridge the gap between the segments to prevent excessive sparking. By referring back to Fig. 24, and the accompanying explanation a clearer idea in regard to this point may, perhaps, be gained.

The armature and field circuits of the dynamo and the connections, together with the lamp circuit are shown in the diagram Fig. 46. Here we have five binding posts, two for the lamp circuit and three that connect to the

regulator. These last are numbered 1, 2, 3, and are connected each to the binding post on the regulator having the same number. In this diagram the current in the outward direction, or more correctly, the positive current is from the binding posts marked, respectively, 1, 3, +, while the returning or negative current enters at 2 and —. The field circuit terminals are at binding posts 1 and 2, while the armature circuits connect to the binding posts at 1, 3, + and —. This, really, is not so complicated or confusing as it may appear at first sight, and although

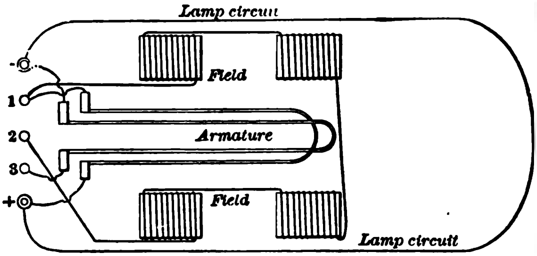


Fig. 46.—Circuits of Schuyler Dynamo.

there are several different circuits, and, perhaps, an apparent inconsistency, still it is quite plain and simple when you understand it, and, in practice, it works well.

We will trace the circuits of the dynamo alone without the regulator and endeavor in that way to get an understanding of it. The lamp circuit runs from + to — binding posts as shown. There are three connections to the regulator, and by this we know that there are two circuits through the regulator, and we also know that two circuits with but three terminals must have one terminal common to both circuits, and as the current is outward or positive at 1 and 3, and negative or inward at 2, we can draw our conclusions from an experiment.

Knowing that there is one circuit outward from 1 and in at 2, we will connect these two binding posts together with a short piece of wire. But when we look at the diagram we see that we have short-circuited the field circuit with a very low resistance, less, in fact, than the resistance of the field circuit, and we know that under these conditions the field never could become charged, so we conclude that the circuit from 1 to 2 must be a circuit of considerable resistance, much more than that of the field circuit, and as we already know that a series dynamo may be made to produce, at will, any current within the capacity of the machine, by a shunt, of variable resistance, across the terminals of the field circuits, we infer that that must be the arrangement in the regulator.

So with a circuit of variable resistance between 1 and 2, we will connect the binding posts 2 and 3 and endeavor to infer, from studying the diagram, what the result will be.

Now, taking our starting point from the + binding post, we trace the path through the lamp circuit to the — binding post and on to the brush and through the armature coil to 3, then to 2, from there through the field circuit to 1. Here we find two paths for the current, one through our circuit of variable resistance from 1 to 2, and the other through the armature from 1 to +, thus completing the circuit.

We see that the circuit would be complete and all the requirements fulfilled if 2 and 3 were connected together and a variable resistance or hand regulator connected between 1 and 2. Then, we ask, of what use is the circuit between 2 and 3? As the regulator is for the purpose of automatically regulating the dynamo, then, evidently, the circuit from 2 to 3 must be for the purpose of controlling

the variable resistance introduced between 1 and 2 at the terminals of the field circuit. Another question we might ask is: "What would be the effect if there was no connection between 1 and 2, and 2 and 3 be short circuited?" Let us trace it out and see. Starting from the + binding post, we follow around to the —, and through the armature coil to 3, and across to 2, and on through the field circuit to 1, and from there through the armature coil to +, where we started from. By this arrangement we see that the dynamo would work at its full power because the full current would pass through the field circuit, energizing the field to its full capacity.

The regulator, with its several circuits and the resistance, is shown in Fig. 47, where *A A* is the solenoid, the armature of which is attached to and works against the retractile force of the spring *K*, which is adjustable and serves to adjust the current on the line to the required amount.

Attached to the armature is a contact piece that makes connection with another contact piece that is hinged just above it. These are shown at *R*.

These contacts have flexible connections to the wires leading to the binding posts 2 and 3 on the dynamo, to the binding posts of the same number on the outside of the regulator box, and from the binding posts 3 and 5 on the inside of the regulator box, and these contacts form a short circuit, cutting out all portions of the regulating apparatus until the current has gained sufficient strength to draw the armature of the solenoid, against the force of the spring *K*, far enough to break this contact at *R*. When the contacts are separated the path of the current is then from 3 along the wire on the right hand side of

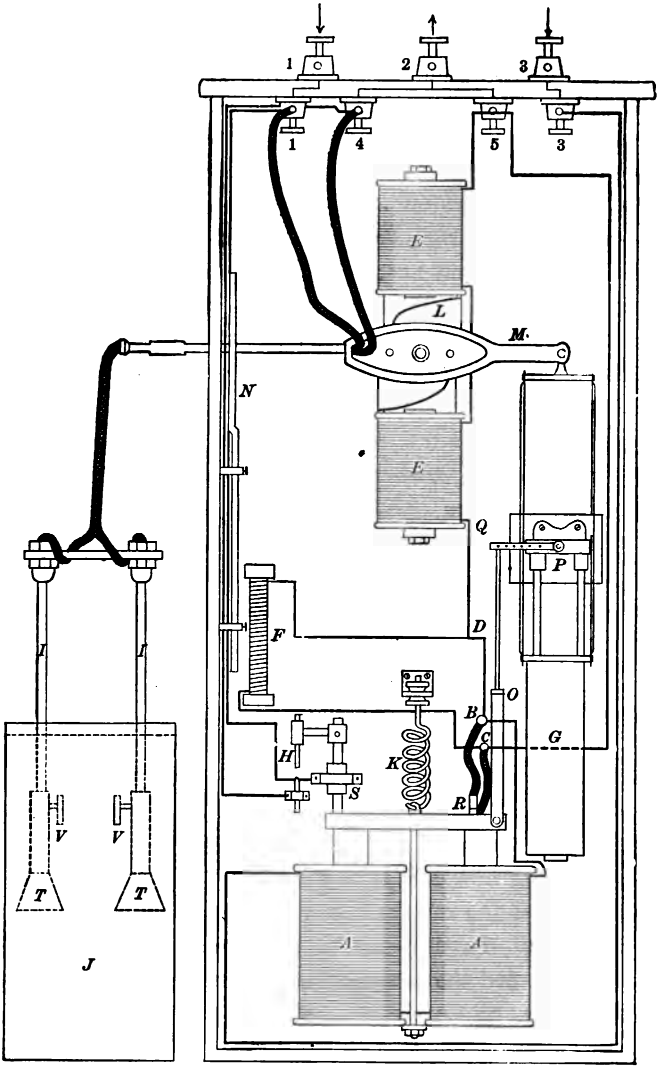


Fig. 47.—Schuyler Regulator.

box, down and across at the bottom, then up and through the circuit of the solenoid *A A*, then up past the connection at *B*—for the circuit at *R* is open—to *D*. Here we find a branch leading off to *F*, which is an open coil of iron wire, and after tracing the circuit from here across to *C* and along to binding post 5, we return to *D* and trace the other branch, which we find forms the circuit through the magnets *E E*, and terminates at the binding post 5 in the same place as the circuit through the coil *F* terminated. After tracing these branches and finding that they end in the same place, we must conclude that the coil *F* is placed there as a shunt for a portion of the current to relieve *E E*; and as there is no other apparent use for *F*, it must be for that purpose. In tracing the other circuit from the dynamo, from binding post 1 to 1 on the regulator and to the inside, we find here two branches: one is a small wire and the other a braided cable which we find enters the hollow arm of the balanced lever *M*, alongside of a similar cable that leads from the binding post 4. From the outer end of the hollow arm the cables drop to the electrodes of the resistance jar, completing this circuit through the solution. The electrodes in the jar have attached to them glass pieces as shown at *T*, and to the parts marked *V*, *V*, rubber tubes are attached and project downward into the solution. The depth to which these electrodes are immersed in the solution determines the resistance of the shunt across the field and consequently regulates the amount of current passing through the field coils and as the magnetism of the field is a necessary factor in the production of the current, any change in this will produce a corresponding change in the current, for the less the resistance of the shunt the greater the amount of current that

will pass that way; and this portion of the current taken from the field will reduce the magnetism and consequently the current produced by the dynamo will be correspondingly reduced.

The magnets *E E*, taking their current from the armature will be affected by any change in the current produced and acting on the armatures *L L*, connected to the balanced beam, vary the position and change the amount of surface of the electrodes *I I* that are immersed in the solution. The dash-pot *G* answers a similar purpose here that dash-pots do in the other systems, that is, to steady the movement of the parts and make the change less abrupt. This dash-pot you will notice is swung by rods from the balanced beam, while the piston rod is solidly attached to the block *P*. The rod *N* is simply an adjustable stop for the purpose of limiting the range of upward movement of the arm of the balanced beam. From the inside binding posts marked 1 and 4 we find other wires leading off, and by tracing them down we find that they end at the carbon points shown at *H*. One of these carbons is clamped solidly in position while the other is held by a clamp that is attached to a rod that slides through a sleeve as shown at *S*. This rod is solidly attached to the armature of the solenoids *A A*, and moves with it. The purpose of these carbons is to form a short circuit across the field if, for any reason, the current becomes so strong that the solenoids would pull the armature sufficiently low to bring the carbons in contact. But you will understand that if the field should be short-circuited in this way that the strength of the solenoids would be immediately reduced and the contact between the carbon points would separate and the field

would become again charged and the points again drawn together.

We will endeavor to gain a better understanding of the action of the different parts and of the circuits through them, by tracing the current from its starting point in the dynamo through the line and the different parts of the regulator until it completes the circuit. In speaking of the starting point of the current, we know that it is a difficult point to determine. The current, at first, is very slight indeed, but as it builds up rapidly, we may suppose that it starts from that portion of the armature that is in connection with the + binding post, as this is the coil that is giving out the highest potential. You will notice, also, that the coil connecting to binding post 3 is giving out a current that leads to the regulator. One of these currents passes over the line, returning to the — binding post, and passing through another coil of the armature leaves the machine at binding post 3, and passing to the regulator enters at 3 and travels on energizing the solenoids *A A*, and making a short circuit through the flexible conductors and the contacts at *R*, leaving, for the present, the magnets *E E* and the resistance *F*, out of circuit. This it does because there is not sufficient strength of current to attract the armature of the solenoids sufficient to separate the contacts at *R*. The current returning at 2 on the dynamo then traverses the field circuit, increasing the strength of the field and reaching the binding post 1, finds two paths open, one through the circuit of variable resistance in the regulator returning to the dynamo at 2, and the other path is through the armature coil where the circuit is complete to the + binding post. As the current increases in strength the attraction of the solenoids cause the

contacts at R to separate, and by this action the magnets E E are brought into operation, but a portion of the current is taken from them through the shunt F, and the continued increase in current strength up to the normal amount passes through these various paths, inversely as their resistance, when the action on the armature L of the regulating magnets causes the electrodes I I to enter the solution sufficiently to reduce the resistance of this circuit and short-circuit a portion of the current from the field circuit. This will, of course, reduce the strength of the field and the current will be reduced in like manner. This will tend to maintain a steady current of a given number of amperes.

When more lamps or other work is thrown on the circuit this action is reversed. The current through the regulator, between binding posts 3 and 2, being reduced on account of more resistance on the line, the strength of the magnets E E are weakened, and the weight of the dash-pot G pulls the end of the balanced lever down, raising the electrodes I I, which decreases the surface immersed in the solution, and increases the resistance of that circuit, causing more current to flow through the field circuit. The field is then more strongly energized and more current is produced. It is the varying resistance of the circuit between the binding posts 1 and 2 that acts to regulate the magnetism of the field and the current produced in the armature. It is the current produced in the armature and passing through the circuit between the binding posts 3 and 2 that governs or regulates the amount of resistance in the shunt across the terminals of the field circuit. By referring to the system of regulation, shown and described in chapter X., you will find a similar method of regulation

but produced in a somewhat different manner and by different apparatus.

In the use of this regulator all contacts must be kept perfectly clean, and all moving parts should be free from all gumminess or stickiness that can in any manner interfere with the utmost freedom of movement of any of the parts. Those parts that have a sliding movement of one within the other require special attention, for you can easily understand that if from any cause their free movement is at all impeded that it will require a greater amount of current to produce a sufficient movement to cause the required variation of resistance in the shunt across the field than is necessary in maintaining a constant current on the line, under conditions of changes in resistance or variation in the amount of work to be done on the line And even when working with a constant load, if the movement of the parts should be impeded in any way it would be necessary for the current to rise considerably above the required amount before the mechanism would move, and then it would move with a sort of jerk that would most probably throw it too far, and this would have the effect of bringing the current below the required amount, and if it did not fall sufficiently low to cause the mechanism to act, the result would be that the lamps would act very badly. In case the mechanism did act under the circumstances, the effect of these changes would be plainly visible in the burning of the lamps, for it would cause the lamps to burn too strongly for a few moments, and then, as the mechanism would be forced to act and the current reduced below the required amount, the lamps would become less brilliant and give a dull, unsatisfactory light that would be very disagreeable by contrast. So it is well,

in the care of a regulator of this kind, to occasionally, at least, examine the contacts and scrape them clean and try the working of the different parts of the mechanism, to satisfy yourself that there is no unnecessary friction at any portion of the apparatus, to, in the least, impede its absolutely free and steady movement.

A large number of electric light plants of good systems and fine workmanship, capable of giving excellent results, have been thrown out and replaced by systems which were no better in any respect, and in some cases not so good, simply because there were some delicate points about it, and the man in charge had been considered as being nothing more than a sort of machine and was given to understand that he must keep his hands off of everything except what he was told to handle, and must not try to understand the mysteries of things that were able (in the opinion of those who put them in) to take care of themselves. It has been considered too often by some graduates in mathematics that the man who wears the overalls is incapable of exercising the reasoning faculty, and many times he has been denied the credit of even understanding the working of a simple machine, by these same individuals. In cases of this kind is it any wonder that systems have been declared failures and have been replaced by others, no better in any respect, but whose principles have been explained to the man who was to make it a success or failure, and they would then prove a success.

But to return to the regulator. If the solution in the jar *J* should become weakened, and it is possible that it may, because the sulphuric acid has a great affinity for moisture, and absorbs it from the air, then it would, perhaps,

be found that the solution had too great resistance, and consequently the lamps would not act in a satisfactory manner, and while looking for a defect in some portion of the system, some one who knew no more as to the exact location of the difficulty than yourself, would come around and, with a sort of spontaneous wisdom, would tell you that you was using poor carbons. Pay no attention to suggestions of that nature but examine all working parts of regulators and those portions of the apparatus on which the regulation particularly depends. Of course, if you do not understand the construction and uses of the different parts it will be a difficult matter to locate troubles, but with an understanding of the principles and a knowledge of the mechanical portions of the apparatus and by giving sufficient attention to the details, successful operation is assured. When working this system under full load, if the machine should occasionally flash you will most probably find the trouble to be located in the jar, and you will possibly notice that the electrodes leave the solution just at the instant that the flash takes place. This will very often produce flashing in dynamos whose regulation is produced by a shunt of variable resistance across the terminals of the field circuit.

The brushes on the dynamo of this system are usually double; that is, there are two brushes connected together, but touching the commutator at different places—one leading the other. The leading brush always carries a small spark, but the brushes that follow should carry no spark at all. If they do, they are not set properly. Soft copper should be used in contact with the commutator instead of the hard rolled copper brushes sometimes used. The reason for this is fully explained in a former

chapter of this book, under the heading of "Commutators and Brushes."

CHAPTER XIV.

THE THOMSON-HOUSTON SYSTEM OF AUTOMATIC CURRENT REGULATION ON ARC-LIGHT DYNAMOS.

In the Thomson-Houston System we find a series wound dynamo of the iron-clad type, but with some distinctive features that are peculiarly its own.

The machine has two tubular magnets, flanged at each end on the outside, and between the flanges the field wire is wound. The inside of the magnets are concaved at each end; one end is shaped to conform to the shape of the armature which is very nearly that of a ball; while the other end, in most of the dynamos, is somewhat similar in shape but has a number of ridges or braces cast inside. These ridges are not for the purpose of strengthening or bracing the magnets, but to add more iron to the mass.

A large quantity of iron in the field magnets of a dynamo or motor is a necessity if good regulation is expected. It is requisite that the mass of iron be so great that it will never be completely saturated with magnetism. For this reason the iron and copper are so proportioned that any current that may be passed through the field coil will never raise the iron to a much greater degree of magnetization than about half saturation. Just the exact amount of magnetization required for the amount of iron, to produce the best results for automatic regulation, is a question that

is not considered as having been settled as yet. Some electricians claim, and build their machines according to the claim, that the iron should be very nearly saturated, while others work on the principle that a dynamo calculated to carry a varying load, should never have its magnets more than one-half saturated. Very good machines have been built after each idea.

The magnets of this dynamo are placed facing each other and nearly enclosing the armature. Iron rods, shouldered near the ends, connect the two magnets and

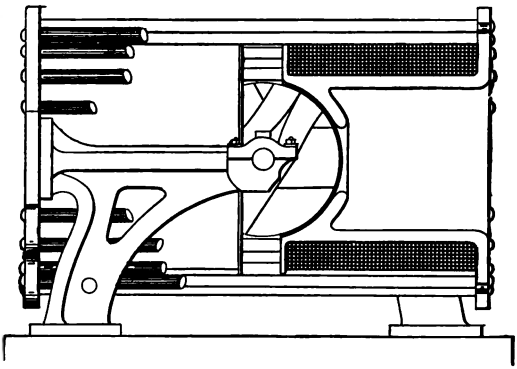


Fig. 48.—Thomson-Houston Dynamo.

hold them in position. The rods fit into holes in the outer flanges, which are made larger than the flange on the opposite end, and are secured by nuts. This arrangement holds the magnets rigidly and allows them to be easily taken apart. A framework to support the machine and give bearings for the armature shaft is also bolted to the magnets. The cut Fig. 48 will give a very good idea of the arrangement.

The armature of this dynamo is of a shape very nearly like a ball. The core is composed of cast iron ribs and flanges. Two flanges fastened to the shaft hold the ribs at the ends, where they fit into a groove in each flange. There are about a dozen of these ribs, and they are wound with a few layers of soft iron wire that is partially insulated. Insulated iron wire gives better results, when used as a core for magnets or armature, than solid iron or uninsulated iron wire. The ribs are insulated from the flanges. The core has a number of wooden pins projecting from it and these are for the purpose of holding the wire in position, for on account of the shape of the core the wire would be very apt to slip out of place if some such means was not resorted to for holding it in position. Before the armature wire is wound on, the core is covered with a few thicknesses of heavy paper to effectually insulate the wire from the core. The armature wire is wound on the core in three equal sections, but in order to bring the wire of each section to the same average distance from the core, only one-half of the first section is laid on at first; then one-half of the second section and all of the third is laid on; then the balance of the second, followed by the other half of the first. This method of winding brings all of the wires of each section to an average distance from the core.

And this is necessary, for if the armature coils should be out of electrical balance—that is if one section of armature wire was nearer the field magnets than another—the result would be an uneven current produced and great sparking at the brushes, or if there was a greater length of wire in one section or if the wire had a different resistance, the result would be the same—great sparking at the brushes. The inner ends of the sections are all connected together

to a collar on the shaft, while the outer ends, which are colored red, white and blue, are led out through a hollow portion of the shaft and connected to separate segments of the commutator. This makes it an open circuit armature, but as two brushes are used on each side, four in all, they serve to keep contact across the breaks in the commutator, and by this means prevent excessive sparking, which would otherwise occur on account of the small number of sections of wire on the armature and their being connected to the commutator in open circuit. The particular reasons for this has been fully explained in a previous portion of this work.

The commutator is in three sections insulated from each other by very wide air spaces, and the copper segments are attached to the iron or brass framework by screws and in such a manner that they can be easily removed or replaced when worn out. They are nicely fitted to the framework, so there is no difficulty in getting them into proper position. The brushes are of sheet copper, slotted and having considerable spring to them. Four brushes are used and are set by a gauge furnished with each machine. Two brushes on each side of the commutator are connected together electrically so that the gap between the sections of commutator is spanned by the brushes. This arrangement short-circuits two coils of the armature whenever the two brushes on one side touch separate sections. This takes place twice during every revolution. Some electricians, pretty well up in the business too, have expressed themselves as being astonished because this style of armature did not burn out oftener on this account. A little careful consideration of the principles and the action of the parts would have shown that there

is but little additional liability of this style of armature burning out any more than many other armatures under the same conditions of operating. When the dynamo is working under a very light load, there is a time during each revolution when the circuit is short-circuited between + and — brushes through the commutator segment, as can be seen by examining the diagram, Fig. 49. It is not advisable to work the dynamo under conditions that would bring the brushes into this position. The position of the brushes on the commutator, and consequently the current produced, is under the control of the controlling magnet,

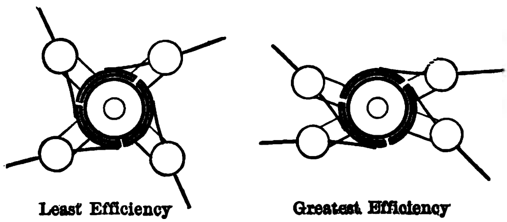


Fig. 49.

the principal parts of which are shown in Fig. 50. The magnet core, *a*, is of wrought iron fastened to the frame, by which it is held in position at the top. The lower end is turned into a shape somewhat resembling that portion of an egg that tapers off to the small end. The armature, *b*, has a hole in it that is of such a shape as to allow the end of the magnet or pole to fit the hole; but as a close fit would not work well at this point, the hole is somewhat larger, so that the metal of pole and armature are never in contact. This allows the pieces to more easily separate when the magnetism is withdrawn, for if they made metallic contact the residual magnetism that remains in

the core after the current is withdrawn would be liable to hold the armature longer than is desired. This provision may be noticed on all electro-magnets and armatures. Some means are provided to prevent the armature and pole-piece from making metallic contact. In telegraph instruments adjusting screws are used. In telephone apparatus a piece of paper pasted on the iron serves to prevent them from sticking together. In electric bells and

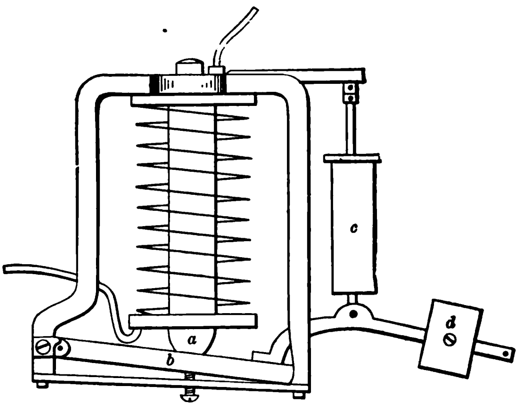


Fig. 50.

annunciators you will find something similar; perhaps a thin sheet of copper, as that is sometimes used for this purpose. In connection with the controller magnet is a dash-pot, *c*. Its purpose is to prevent sudden or violent movement of the apparatus or of the brushes to which it connects. The weight, *d*, on the lever is a means used to bring the brushes to the position of greatest action, if not otherwise controlled by the action of the current on the controller magnet. The brush holders of both of the leading brushes are attached to but insulated from a brass

bar that works on the shaft for a center and keeps the brushes in a position directly opposite each other at all times. The other brushes are connected by a similar bar. Remember, these bars have no electrical connections, for each brush holder is insulated from the bars, but the connection is merely a mechanical one, and its purpose is to keep the brushes in a position exactly opposite. The brush holders of each pair of brushes are electrically connected.

Between one pair of brush holders there is a mechanical connection of levers and links that derive their movement from the lever connected to the armature of the regulator magnet. This mechanism is so arranged that when the leading brush is pushed ahead the other brush is drawn back. When the leading brush is drawn back into a position of greater action, the following brush is advanced into a position of greater action also. The idea (explained in another place) is that when the brushes are moved into a position of less action, or, in other words, when the current is to be reduced, the pair of brushes are separated, and when the current is to be increased, they are brought nearer together.

The action of the regulator magnet on the brushes is such that when the armature is drawn up, or attracted, it moves the brushes to a position of lesser action. This movement of the regulator magnet is brought about by the operation of the wall-controller shown at the upper left hand corner of Fig. 51. The wall-controller consists of two solenoids with a single armature connected to the cores, *B*, *B*. There is an adjusting spring connected with the armature at one end and to the yoke piece at the other. This spring may be so adjusted that the amperes of current

can be varied between certain limits. Fastened to the under side of the armature is a platinum contact piece that makes contact at C with a strip lying horizontally. Platinum is used on connections of this kind in nearly all electrical work where the current is frequently broken by the separation of the parts. Platinum is not easily oxydized, and for this reason is more serviceable than any

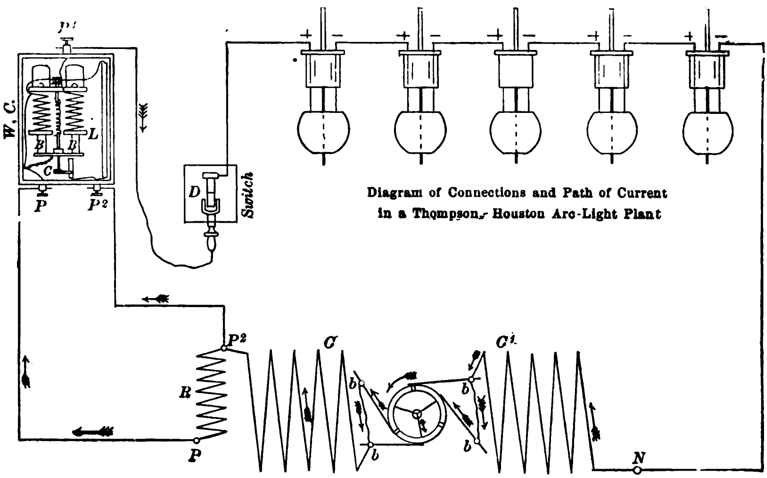


Fig. 51.

other metal for this purpose. When the circuit is broken between two contacts, the action of the current on the contacts, as it jumps across the space, forms a slight film of oxide that has a very high resistance, and as each spark is produced the film of oxide increases, and consequently the resistance is increased. As these contacts are continually making and breaking this shunt circuit, while the dynamo is in operation, and as there is a slight spark

at each break, any other metal than platinum would soon become considerably oxidized, and interfere with the regulation. At L is shown a glass tube containing a rod of carbon that is used as a resistance. There are three binding posts attached to the wall-controller, and marked on the diagram P, P^1, P^2. The circuits through the wall-controller may be traced from the binding post P, upward and through the coils of the solenoids to P^2. But you will notice that a branch has been led off through the piece of twisted cable to the armature of the solenoids. Another circuit through the wall-controller starts at P^2 and passes through the carbon resistance L, and across to the opposite side, where it is joined to the wire forming the coils of the solenoids; but a branch has been led off from this circuit, just where it entered the box, and leading to the horizontal contact piece. Through this path a short circuit is made by way of the contacts at C and the twisted or cabled wire to the circuit leading from P. By examining the diagram and tracing the circuit from the binding post of the dynamo P^2, which is the terminal of the dynamo, we find the circuit separates here; one portion going direct to the wall-controller at P^2 and across the short circuit through the flexible conductor, and there joining with the other portion of the circuit that has gone through the regulator magnet coil P.

When these two circuits join in the wall-controller they then lead through the solenoids and out at P^1, and from there through the switch or circuit-breaker D, to the lamp circuit and from there to the machine again, where it enters at the negative binding post N. Entering the field circuit at N, it passes through the coils of one magnet C' and through the armature by way of the brushes b, b, b, b,

and through the other magnet coil *C*, and to the positive binding post again. When the dynamo first comes into action, the brushes are in a position similar to that shown in Fig. 49 as the position of greatest efficiency. The armature of the regulator magnet is at its lowest position. In the wall-controller, the armature is down and the contacts at *C* are together. With these in this position you will notice that there is a short circuit for the current from the binding post at the top of the regulator magnet marked P^2, to the binding post P^2 on the wall-controller and through the contacts at *C*, and the flexible connection to the wire at the left of the solenoids.

The greater part of the current passing through this circuit cuts the regulator magnet out of action, and leaves it out of action and the brushes on the commutator in the position of greatest action until the current has increased to the required number of amperes.

As soon as the current reaches this amount the armature of the solenoid is first acted upon and attracted. This separates the contacts at *C*, and forces a large portion of the current through the coils of the regulator magnet *R*. But all of the current cannot yet pass that way, for you will see by examining the diagram that a large proportion also must pass through the resistance *L*.

As soon as the contacts at *C* are separated and a greater portion of the current is caused to pass through the regulator magnet, then its armature is raised—not suddenly, for that would be liable to cause the dynamo to flash, but slowly and steadily, for there is the resistance of the dashpot to be overcome, and this mechanical resistance causes the armature to move slowly, and its action through the levers and links moves the brushes to a position of less

action and the current is reduced in proportion. The armature in the wall-controller should then move slowly downward until the contacts at *C* are again together, when the regulator magnet being cut out of action, the weight on the extension of its armature causes the brushes to be slowly moved into a position of greater effect, and as the current is again increased the contact at *C* is again broken and the same action is continuously repeated while the dynamo is generating current.

If the dynamo should be overloaded, the solenoids in the wall-controller would not have sufficient power to raise the armature and break the contact at *C*, consequently the regulator magnet would not be called into action and the weight would hold the brushes in the position of greatest action.

When this dynamo is running under too light a load (which should never be permitted), the brushes are thrown into a position where the current from the armature is short-circuited between a + and — brush. This position is shown in Fig. 49, where the brushes are shown as being in a position of least efficiency. The short-circuiting between a positive and negative brush is only momentary, but its effect, if continued for any length of time, may produce results that are not at all desirable, and for this reason should never be permitted. Another thing that is quite noticeable about this dynamo and that might readily be expected, on account of the small number of sections in the armature, is the sparking at the commutator. Large sparks are continually formed as the leading brushes are separated from each segment of the commutator. But this need not occasion any alarm, for admirable means

have been provided for reducing the sparking to a condition where no harm can result from it.

A blower is attached to the shaft, and tubes leading from it convey a blast of cold air to the commutator, where it strikes about $\frac{1}{16}$ inch in front of the end of the brush, and in such a direction that the blast blows the spark out before it attains too great a length. An oil cup is attached to the blower by which the fans may be kept

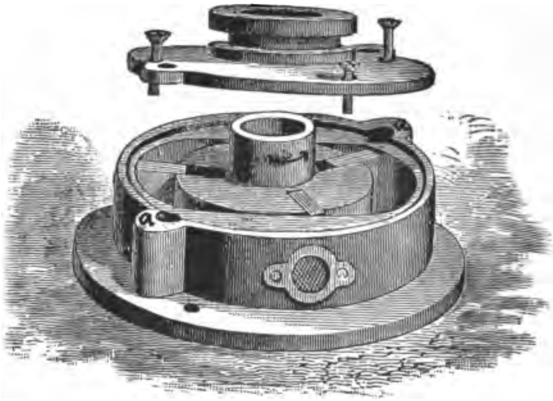


Fig. 52.

well lubricated, and any surplus of oil fed to the blower is carried through and on to the commutator segments, where it prevents the cutting of brushes.

But reliance should not be placed on this for keeping the commutator and brushes from cutting. The commutator should be frequently wiped with an oily rag, while running, care being taken that the rag is not pulled away by being caught on the corner of the commutator segments.

The blower is shown in Fig. 52, and consists of a disc, slotted radially with three slots, in each of which are

placed a square of iron that fits sufficiently loose to allow the tangentical energy to keep it in continuous contact with the sides of the chamber in which the fan is placed. This chamber is of elliptical shape, and the fans, at two places during a revolution, are forced towards the center of the disc until they do not project at all. In this position they pass an opening where air is admitted and the space around the disc grows larger. This allows air to be drawn into the space, which is compressed as the fans reach a narrower part, and from there it is forced through the openings *a*, *a*. The tubes leading to the commutator are connected to these openings.

The cut shows the construction sufficiently well to be understood with the short explanation given.

This dynamo, like most others, sometimes gets a fit of flashing, and the causes for a dynamo's flashing were all written out by an employe of the company and sent to the men in charge of dynamos of this kind. It is presumed that all parties using these dynamos received a copy. The list of causes was quite numerous, but it has been said that it was not half complete, though it covered all conceivable portions of the whole system. If you are running a dynamo of this kind and it gets to flashing, you can probably find the cause for it on the list, if you have one ; if not, it can be obtained from the company. If you cannot get the list, you might see if any of the five causes for flashing, given in a previous chapter of this book, can be found in your dynamo.

There are but few things about this dynamo that require special care. But on any dynamo or motor it will be found that commutator segments and brushes require the most attention. A good smooth commutator is essen-

tial to good work, and to keep the commutator in good order requires that it should be in good shape and the brushes properly set.

The dash-pot may, if the glycerine in it be too thick or too thin, give some trouble at times by causing the lamps to give an unsteady light. But this would be easily noticed and as easily corrected. By kèeping the circuit free from leaks or grounds, and keeping everything connected with the system clean and free from oxidation, but little trouble will be experienced.

CHAPTER XV.

THE WATERHOUSE SYSTEM OF THREE-BRUSH AUTOMATIC CURRENT REGULATION.

In this system we have a dynamo of the Manchester or consequent pole type, series wound, and standing in a vertical position. The cylinder armature is connected in closed circuit. The peculiar feature of this system of regulation is the third or auxiliary brush, which is supposed to play an important part in this system of regulation. By referring to the cut, Fig. 53, where *M*, *M*, *M*, *M*, shows the magnets, and the armature is shown at *A*. The commutator is marked *C*, and the brushes *a*, *b*, *c*. You will notice that two of the brushes, *a* and *b*, occupy the same position on the commutator of this dynamo as on most others, that is, at positions directly opposite. The auxiliary brush *c*, is set somewhat in advance of the upper brush *a*, but still within the limits of the point of lowest commutation. The point of lowest commutation in most dynamos is at that point on the commutator that connects with that section of the armature wire that is just entering the opposite field from which the current was generated; while the point of highest commutation is at that point where the wire is just leaving the field.

In the cut, brush *c* shows very nearly the point of lowest commutation, while brush *a* is very near to the point

of highest commutation. The point of commutation varies according to the magnetic intensity of the field; being farther back for the more intense field and farther forward for the less intense field. One explanation of the reasons for the change of position of the point of commutation under varying loads was given at some length, in a former chapter of this book.

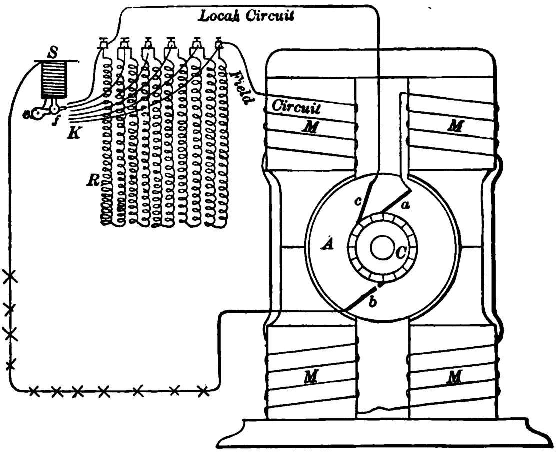


Fig. 53.

Now it may be easily understood that as the brushes cover these two points, all changes in the load will still keep the point between the main and auxiliary brushes. But to keep the regulation as nearly perfect as possible a series of resistances are necessary, and a fair idea of their operation may be gained from the other portions of the regulator shown at upper left hand corner of the cut. The resistance coils are represented at *R*. These may be of iron wire, German silver or any other material that will

answer the requirements. The cut does not show the exact construction of the rheostat, but it is sufficiently close to give a comprehensive idea of the working of the regulator. A solenoid *S*, whose core is attached to the lever *f*, is connected into the circuit as shown. The resistance coils *R*, are connected by branches to the commutator *K*, as shown. In actual practice this commutator is confined to a very small space, and a slight movement of the core of the solenoid is sufficient to cause the end of the lever *f*, to move from one extremity to the other, thus throwing more or less of the current through the field circuit or through the local circuit. You will notice that the resistance coils are connected at one end with the circuit through the fields, while at the opposite end they are connected to a short circuit leading from the auxiliary brush *c*. While the dynamo is in operation all of this resistance is divided between the field and local circuits, according to the resistance in the main circuit. Supposing the current required be ten amperes, regardless of the number of lamps or the amount of other work on the line, then the action of the regulator would be about as follows: Starting the dynamo into action with a light load or small resistance on the line, the core of the solenoid extending out of the coil, and the end of the lever *f*, in contact with the lower bar of the commutator *K*, would make the circuit through the field of much less resistance than that through the local circuit. For when the lever *f* is in contact with the lower bar of the commutator *K*, all of the resistance coils *R* are thrown into the local circuit, consequently the greater part of the current produced will flow from the brush *a*, directly through the field circuit and past the resistance *R*, by way of the branch, to the lower

plate in the commutator *K*, and by way of the lever *f* to the contact at *e*, thence through the coils of the solenoid to the main circuit, and returning to the machine through the brush *b*.

With low resistance on the line, and the greater part of the current flowing through the field circuit, the electro-motive force will soon produce ten amperes of current on the line, and the solenoid, being brought into action and the lever *f* raised, resistance is cut into the field circuit, and the resistance of the local circuit is reduced a corresponding amount, consequently, the current passing through the field circuit is lessened, and the magnetism of the field decreased, and the amount of current produced is diminished. As resistance is cut out of the local circuit, a greater portion of the current will pass that way; but the current on line can never raise to more than ten amperes, for as it passes through the solenoid the lever would be acted upon and more resistance would be cut into the field circuit, until there would not be sufficient current passing to create magnetism enough to generate the necessary electro-motive force.

When more resistance is thrown on the line the current will fall, the solenoid will cease to hold the lever, and as the lever falls and passes over the commutator strips, resistance will be cut out of the field circuit, allowing more current to pass that way, increasing the energy of the field and the electro-motive force at the same time. You will, no doubt, infer from the foregoing analysis of the three-brush regulation, that the regulation is produced not so much by the brushes as by the amount of current passing through the field circuit. It will appear that the brush nearest the point of commutation, for the amount

of load on the line, is the one that will take away the greatest amount of current, and if the resistance of the field and local circuits were the same, this would no doubt be the fact; but as we know that the resistance of a circuit is the sum of all the resistances in that circuit, we find that it is necessary, in order to produce perfect and instantaneous regulation, to have a variable resistance in both the local and field circuit, and that the variability of these resistances must be under the control of mechanism operated by the full current on the line. This we have in this system in the rheostat or resistance coils and the solenoid.

This system, while being unique, is, nevertheless, very sensitive and extremely accurate, and as far as can be ascertained, has given excellent results. The third brush. takes care of the sparking at the commutator in such a satisfactory way that no change in the position of the brushes is required under any change of load or change of speed. In the care of this machinery, the same points so frequently mentioned in this book as necessary in the care of any dynamo-electric machinery will apply equally well here.

With this chapter we will close the subject of automatic direct current dynamo regulation, and give a short description of some of the current indicators in use on some of the systems. In most systems using automatic current regulations it is not thought necessary to use a current indicator of any kind, for it is claimed that the automatic apparatus will take care of the current and keep it all right. Our private opinion is that this is a mistake, for there are very few pieces of automatic apparatus but which will require occasional testing and adjusting, and it is noticeable that those attendants who have the best instru-

ments for testing and adjusting are the most successful with their machinery, if they make frequent use of these instruments and act in accordance with the knowledge gained by their use. Exceptions to this statement may no doubt be pointed out, but it can be taken as a general rule, and it may be further stated that there is hardly an electric light plant in the country which is giving poor service but which might have been kept in a satisfactory working condition, if the attendant had been provided with apparatus for testing and adjusting.

In all series systems, whether it be arc or incandescent lamps or motors, it is usually termed a constant current circuit, and if a constant current is what is required, there certainly should be some instrument for measuring the current. Automatic regulators may do it all right—some lack considerable of doing it—but if there is an instrument handy for verifying what the automatic regulator is doing, so that it is known that that part of the system is all right, then trouble of any kind, if it occur, can be the more easily located.

CHAPTER XVI.

AMPERE METERS.

The amount of current flowing in the circuit is usually measured in amperes. We have explained in a previous chapter what is meant by an ampere; but we will say here that an electro-motive force of one volt flowing through a resistance of one ohm will produce one ampere of current. An ampere of current cannot be taken by itself alone, for it has no existence except as a result of two other principles, electro-motive force and resistance. Without both of these factors, a current of electricity would be unknown and there would be nothing to measure. When electromotive force passes through resistance then the current is developed and we have something to measure; this something we measure in units called amperes, or if the amount is smaller than an ampere; it is measured in units of one one-thousandth part as great. These smaller units are called milli-amperes, but we do not get down quite that fine in electric lighting. Notwithstanding the fact that we cannot isolate an ampere of current from the factors, E. M. F. and resistance, yet an ampere of current will do a given amount of work, will decompose a given weight of water, will deposit a certain amount of metal in an electrolytic bath, and there are many things that it will do that enable us to determine just how much an ampere of current is.

Some of the simpler forms of instruments for measuring the amperes will be explained and illustrated. In Fig. 54 we have a very simple form of ampere meter, or ammeter, which consists of a strip of copper about 1¼ or 1½ inches wide, fastened to a block of wood, guttapercha, vulcanite

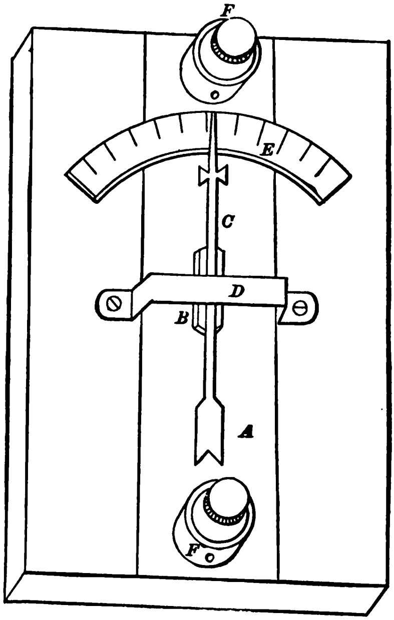


Fig. 54.

or other insulating substance, as shown at *A*; a piece of magnetized steel, *B*, to which a needle, *C*, is attached.

A scale is provided from which the number of amperes passing can be read. The armature *C*, is held in place by a pivot that passes through its center and works in delicate bearings at each end. The needle, which should be of

brass or other non-magnetic metal, is rigidly attached to the armature B, and moves with it.

The philosophy of the action of this instrument is, that when a polarized piece of steel is brought near to a conductor through which a current of electricity is passing, the polarized steel tends to set itself at right angles to the path of the current. The stronger the current may be or the lighter and more highly magnetized the armature may be, the nearer to a position at right angles the armature will assume.

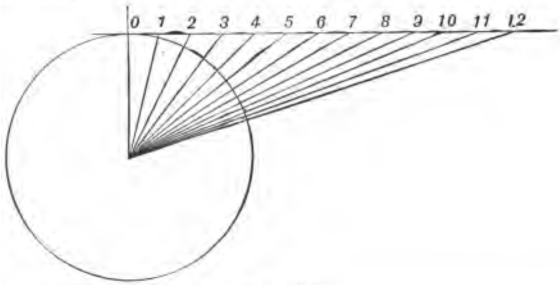


Fig. 55.

It is not really practical to make an instrument of this kind to cover a range of much more than one-half of a right angle, for when the needle moves to an angle of about 50 degrees it will require a much greater increase of current, in proportion, to move it through another degree. This may be better understood from a tangent scale as shown in Fig. 55, where a given amount of current will move the needle through one division of the scale, and the addition of an equal amount will move it through another division, and so on. But you will notice that the divisions on the circle become smaller and smaller after about four divisions have been passed. After that it requires an equal

increase of current to cause the needle to move to the next mark, although the distance is not so great. The reason for this seems to be that the pull of the current, if we may call it such, is more at an angle, and the same force of current acts more at a disadvantage. There are several things that the ammeter will call our attention to on series systems. One of the things is, leakage on the line; another is, increase of resistance in the circuit from any cause.

If the current fail to keep up to the standard, or to the full number of amperes while the dynamo is running at its usual speed, we will immediately infer that something is wrong. A test for leakage or grounds should be immediately made, and if no leakage is detected we may then suspect an increase of resistance, possibly from corroded or loose joints. But this last difficulty is not so frequent now-a-days as it was four or five years ago. Then telegraph and telephone line-men did most of the electric light wiring, and for a large day's work that was sure to give trouble afterward, they were entitled to a prize.

Joints in electric light or motor circuits cannot be too well made and the more care given to them at the beginning the less trouble there will be afterwards. But it is just as necessary to *know how* to make a good joint as it is to exercise a great deal of care in the making of it. With an arc light circuit, if the current is kept to the required amount and the lamps do not burn satisfactorily you may infer that the trouble is in the lamps, and most probably a sticky coating has formed on the rod, and the lamp trimmer has failed to attend to it.

Ammeters are of low resistance, and are connected into the circuit in series.

The indicator shown in Fig. 56 is a solenoid ammeter, consisting of a helix of coarse wire, *a*, wound on a brass tube, *d*, having a cap at the top, and a reducer screwed on to the bottom.

The core, *b*, is a soft iron tube suspended by a light spiral spring *c*, from the adjusting screw, *e*, that is threaded through the cap.

From the core, *b*, a strip extends upward, that carries at its end a marker, *j*, that shows upon the scale the number of amperes of current passing through the instrument. The rod marked *f*, serves as a guide for the core, and keeps it in the center of the tube.

A casing, *h*, covers the upper part of the instrument, protecting it from injury and dust.

This casing has an oblong opening cut in one side through which the card on which the scale is marked, can be seen. This opening is closed by a piece of mica.

The whole is fastened to a block, as shown in the cut, though some are fastened to a bracket, which may be attached to the wall. The binding posts carry the terminals of the wire coil, and serve to connect the ammeter in circuit. This is a neat little instrument, and is very convenient in the dynamo room.

The principle of this instrument is that of a solenoid. Electro magnets and solenoids are nearly alike in their actions, but an electro magnet has a stationary core, while the core of a solenoid is freely movable. Anything that interferes in the least with the free movement of the core, will seriously interfere with the action of the instrument, and care must be used in placing the instrument, to get it in a vertical position. The action of this ammeter depends upon the principle that when an insulated wire is wound

into a helix, and a current of electricity is passed through the wire, an iron rod or tube, if introduced into the opening, will be attracted with considerable force. If the iron be of the same length as the helix, and the current be strong enough, the iron will be drawn wholly within the helix, and held suspended apparently in the air. In fact,

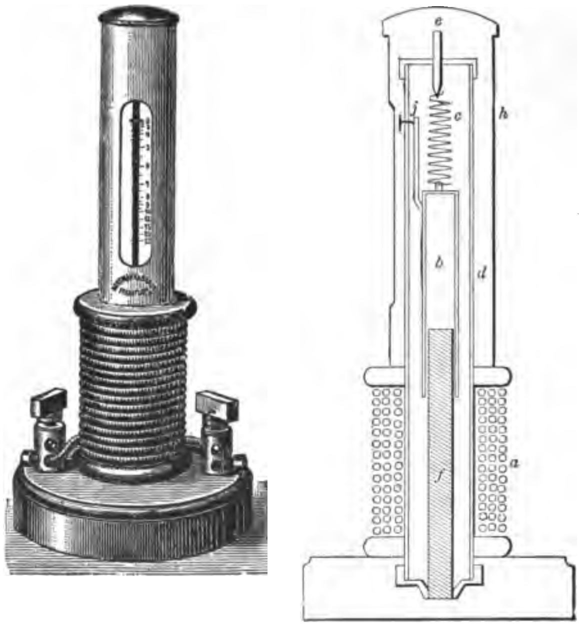


Fig. 56.

a solenoid has about as much strength as an electro magnet of the same size. In the solenoid ammeter, Fig. 56, the core is held by a spring, and the attracting force of the helix pulls the core downward with a force in accordance with the number of amperes of current passing, and the number of turns of wire in the helix. You will

understand that if there are one hundred turns of wire, and one ampere of current flowing, there will be one hundred ampere-turns, while if there are but ten turns of wire, and ten amperes of current flowing, there will still be one hundred ampere turns, and the attractive force will be the same in either case. The wire carrying the current in an ammeter, should be large enough to carry all the current that the ammeter will measure, without heating too much, for the heat will increase the resistance, and the resistance will require electro-motive force to overcome it. In this ammeter (Fig. 56), if it is not placed in a perfectly upright position, the core will bind on the guide rod, enough to prevent its giving a correct record.

There is another feature about the solenoid indicator that is worth more than a passing notice, and is somewhat similar to that shown in the ammeter, Fig. 56, and that is that the divisions on the scale are not equal.

When the core has entered the helix but a short distance, the pull on the core for a given increase of current is less than when the core is farther in, and under the influence of a greater number of turns of wire.

If the core be of the same length as the helix, it will be drawn in with increasing force, or to a greater distance with each increase in the amount of current passing, until the core is about one-half in the helix, where it will be found that the helix gives its strongest pull for a given amount of current. With an increase of current, the pull is increased, and it appears that when the end of the core has passed the turns at the center of the helix, that each additional turn acted in opposition to the others, and makes the distance traveled decrease slightly for each given increase of current. The above explanation may enable

you to understand why the divisions near the ends of the scale are narrower than those near the center.

Fig. 57 shows another form of the solenoid ammeter. In this ammeter the iron core is placed in the brass tube, at the bottom of the instrument, where it fits loosely. A

Fig. 57.

brass or German silver wire attached to the core, and extending upward, carries a marker at its end. The principle of this instrument is precisely similar to the one just described. The core is drawn upward against the force of gravity instead of being drawn downward against the force of a spring, as shown in Fig. 56.

Another kind of ammeter on the solenoid principle is shown in Fig. 58. In this instrument the helix is of bare wire and wound in open coil. It is curved to the segment of a circle the center of which is at the pivot, on which one end of the core, which is bent around to an acute angle, is suspended. A pointer is added which projects downward to the scale. The helix is sometimes made of

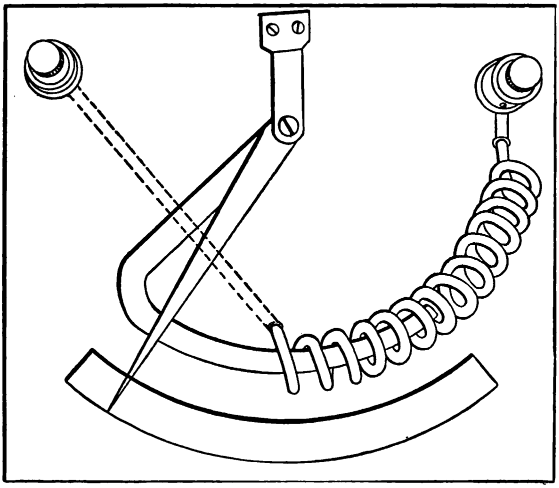


Fig. 58.

copper rod of square section, or is cast to the shape required. Being of open coil it is not necessary that it be covered with an insulating substance for the air spaces between the turns are an excellent insulator, although not the best by any means, as there are several substances that possess better insulating qualities than air. Air, on account of its absorbing moisture so readily makes its resistance much less than that of many other materials.

The air spaces in an ammeter of this kind fully answer the requirements of insulation, for this is a heavy current ammeter and generally heavy currents are used at a very low potential so that there is not much chance for leakage.

The ammeter shown in Fig. 59, designed for heavy currents, consists of a flat copper bar, *A*, bent into a form

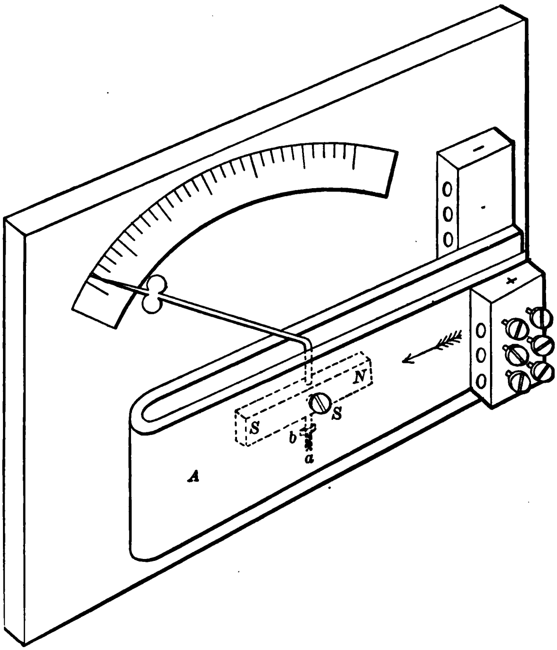


Fig. 59.

somewhat resembling a horseshoe, when looked at from the narrow side. The binding posts marked + and — are heavy blocks of brass firmly attached to the copper bar, and the joints are made for good electric conductivity. Several holes are provided by which more than one wire

can be attached. The principal object of this is to use smaller wires and more of them to carry the current, for one wire large enough to carry the full current without heating would be too large to get into shape conveniently. It is quite commonly the practice to use several small wires, when heavy currents are to be transmitted, instead of one large wire, because the small wires cost less and are more easily handled, besides giving greater radiating surface which prevents them becoming too hot, when a single wire of the same length, and containing the same weight of copper, would become dangerously hot if carrying the same number of amperes of current. The armature is a piece of hardened steel polarized and placed with the poles as shown, *N S.* The armature is free to move, being balanced on two hardened points that work in the counter-sunk ends of two adjusting screws that pass through the sides of the copper bar. One of these screws is shown at *S.* A threaded rod, *a*, carrying a burr, *b*, projects from the under side of the armature. This is for the purpose of adjusting the calibration of the instrument. The action of this ammeter depends upon the principle that when a polarized piece of steel, if free to move, is placed near to a wire carrying a current of electricity, the polarized steel tends to set itself at right angles to the path of the current. It has been noticed that the end of a polarized bar that points to the north, when allowed free movement, the one marked *N* in the drawing, will always move to the left from the direction in which the current is flowing, if held *under* the conductor; while if held *over* the conductor, the *N* end will always move to the right. In the drawing the direction of the current is shown by the arrow, and you will notice that from that part of the conductor on the side next to

to you, the armature is in the same relative position as though it was under the conductor while it would be over the other part. With the current passing in opposite directions on the opposite sides, the influence is combined to move the armature in the same direction. If the current is passed through this ammeter in the wrong direction, or opposite to that shown, then the armature would move in the opposite direction, but it could be easily arranged to work correctly by simply loosening the screw *S*, taking the armature out and turning it end for end, and turning the pointer until it leaned toward the other end of the armature and replacing it again in position.

Another style of simple ammeter is shown in Fig. 60. This instrument consists of a box frame made of any non-magnetic material around which the wire is wound, the ends of the wire being connected to the binding posts, *B B*. The armature of this instrument may be of soft iron or polarized steel. The principles of its working are similar to those described in connection with Fig. 59, that is, that the armature tends to set itself at right angles to the wire through which the current passes This style of instrument, with the numerous turns of wire is designed for light or medium currents. The scale is laid off from the center both ways, so that with a polarized armature it is immaterial in which direction the current passes through it, as the only difference it would make would be to cause the pointer to move to the opposite side of the scale. In some respects this would be a very good arrangement, for, if the dynamo should change its polarity—as some of them occassionally have done, although it seldom occurs—the position of the pointer would immediately show it. It is also quite easy to tell the direction of the current when this ammeter

is connected into a circuit. With a soft iron armature this ammeter would work equally well, but the pointer would be as liable to move to one side as to the other when the current was passed through the coil if the armature

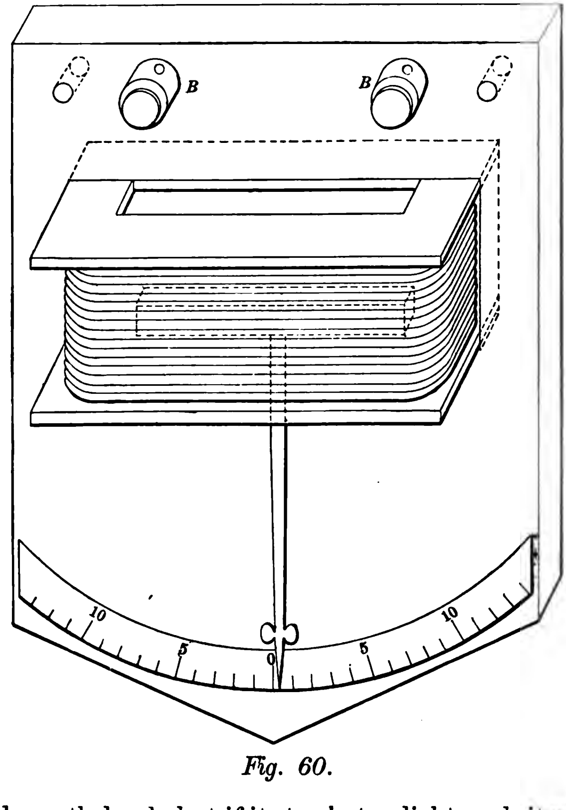


Fig. 60.

stood exactly level; but if it stood at a slight angle it would then move in the same direction regardless of the direction of the current through the coil. The inductive influence of the current will polarize a soft iron armature as long as

the current is passing, but when the current ceases the iron loses its magnetism—not all of it, but the softer the iron the less magnetism it will retain.

All of the ammeters shown in this paper are designed to be kept continuously in circuit, and they will stand it without injury. They are practically correct, and some such instrument should be kept continually in circuit, on all constant current circuits, if best results are desired. An ammeter is as necessary to a constant current circuit as a steam gauge is to a steam plant. You can get along without either, but the results will be neither economical nor altogether satisfactory. There are various other systems of ammeters, working on other principles from those explained here, but enough has been given to convey a practical idea of those intended to remain in circuit. Some are intended to be used only as standards for comparison. The use of iron or steel as part of an electrical indicator is to be avoided as much as possible for the steel will gradually lose its magnetism and will be affected by outside influences to a certain extent. The soft iron armature, when polarized, as it always is under the conditions of use, is affected more or less by a mass of iron near it, or by the magnetism from dynamos when near by. This defect does not render them useless, by any means; but occasional comparison and recalibration, when necessary, should be made. They are a very necessary adjunct to an electric light plant.

CHAPTER XVII.

VOLT-METERS AND POTENTIAL OR PRESSURE INDICATORS.

In the last chapter was described and illustrated a few of the simpler ammeters that are designed to be kept continuously in the circuit. The illustrations and description cover but a very few of the different kinds of ammeters made, as it was not intended to cover the whole field, but simply to give a comprehensive idea of some of the principles upon which these instruments work. In this chapter we will try to make plain the mechanism and action of a few of the volt-meters and pressure indicators that are in common use with some of the systems of lighting. In the construction of volt-meters one thing is absolutely necessary; that is, that they be of high resistance, while with ammeters it is necessary that they be made of low resistance. This may be easily understood when we remember that volts represent pressure. Volt-meters are for measuring this pressure, and are always connected in multiple arc, or between the mains when it is desired to measure the effective electro-motive force or difference of potential of a circuit. To find the fall of potential or loss of volts that takes place in any part of the circuit, whether it be an arc or incandescent lamp, motor, storage cell or battery, or anything else that consumes the force of the current, a loose or badly made joint, for instance, the volt-meter is

then connected in shunt, or parallel with the object. To make this more clear, we will consider that it is desired to measure the fall of potential in an arc lamp, or in other words, how many volts of E. M. F. are consumed in the lamp. To do this it is necessary to simply connect the lamp in circuit with a dynamo producing sufficient current to give to the lamp a full arc, then connect the volt-meter to the binding posts of the lamp and take the reading of the instrument, when, if it be a direct-reading volt-meter, the figures will give the number of volts lost, or, in other words, the fall of potential. The reason why the measurement can be made in this way may, possibly, be better understood when we make a little comparison between the resistance of the lamp and the resistance of the volt-meter. The lamp has, we will assume, a resistance of one and one-half ohms, while the volt-meter has a resistance of from 1,000 to 20,000 ohms. Suppose the resistance to be 1,500 ohms, and the form of the instrument to be similar to that shown in Fig. 56, though the form is immaterial. Now if the lamp and volt-meter be connected in shunt or parallel, the current passing through each will be inversely proportional to their respective resistances—that means that where the less resistance is, there the greater amount of current will pass, and where the resistance is greatest, the least portion of current will flow through that path. Now if the resistance is 1,500 ohms, in one part, and but one and one-half ohms in the other, it is evident that only about 1-1000 will pass through the volt-meter. This being the case, we know that the amperes, or part of the ampere of current that flows through the volt-meter would not have very great attractive force on the armature or core of the instru-

ment unless there were a great number of turns of wire to multiply the attractive force of the current.

In making a measurement under the conditions mentioned above, we should, quite probably, find that the reading of the volt-meter gave 30 as the loss of potential. Then if we were to examine the length of arc at which the lamp is burning, we would be very apt to find it somewhat less than 1-16 of an inch. An ammeter in the circuit would, of necessity, show, if it was correct, between 18 and 22 amperes. With so short an arc—an arc of low resistance—there must be a very heavy current in order that the carbons be heated sufficient to give a good, full light. If the fall of potential of a lamp measured, say, 45 volts and was burning with a clear white light and the arc was just about ⅛ of an inch long, we would expect to find the ammeter registering a flow of current of 9½ amperes. It might vary some, perhaps ½ ampere either way from this amount.

A volt-meter of the form of Fig. 56 or Fig. 57, would be found very useful if wound with about 1,800 ohms of wire of such a size that that amount of resistance would about fill the spool. Volt-meters are also made in the form shown in Fig. 58, and they may be converted into a pressure or potential indicator, for constant potential systems, by placing them in a horizontal position and using the force of a small magnet, placed near enough the armature to exercise sufficient influence to bring the pointer to the center of the scale when the potential is of the required amount. This small magnet is adjustable so the indicator may be made to stand at zero with a current of any desired potential, within the capacity of the instrument.

The Howell pressure indicator shown in Fig. 40 is constructed on the principle of an electric balance with the additions of a field of variable resistance and an incandescent lamp introduced into the circuit.

There are volt-meters that are constructed on the principle of a magneto and others that are somewhat similar in principle to a dynamo.

A steel horse-shoe shaped magnet forms the field and a drum armature, of soft iron, with but one section of wire wound upon it, carries the pointer. The armature shaft works in jeweled bearings, and the current is carried to the coil on the armature through flat spiral springs which are also the retractile force against which the armature pulls. A spool of fine wire is placed in series with the armature, between the binding posts, which gives the required resistance, which in this case amounts to 20,000 ohms, according to the manufacturers statement. An instrument having a resistance of 20,000 ohms might be safely used to determine the potential between the binding posts of the largest high potential arc light dynamos that we have in use in this country, although it might be destructive to the instrument if left in circuit, for more than two or three seconds, with some of the fifty or sixty arc light machines.

A potential or pressure indicator built on the principle of a dynamo, consists of a field almost exactly like that of a consequent pole dynamo, but laid flat instead of standing upright—a matter of convenience only. Four coils of wire form the field coils as usual in consequent pole machines. A soft iron armature core of the drum type wound with a single coil of wire and suspended by a brass wire from a brass standard, which forms a part of the circuit through the armature coil. The other terminal of

the armature circuit is a platinum pin extending from the lower end of the core and dipping into a cup of mercury, which is also a part of the circuit. The adjustment is made by a milled screw that passes through the upper part of the standard, and carrying at its lower end the wire by which the armature is suspended. A slight turn of the screw produces a twist in the wire that requires more current to overcome, while turning the screw in the opposite direction assists the current. A description of the working of the whole apparatus would show that the resistance of both field and armature circuits, whether connected in series or shunt, is comparatively a high resistance, and the current passing through magnetizes both field and armature, and the action is then similar to that of a motor or the reverse of a dynamo. There being but one coil of wire on the armature there is, of course, no use for a commutator, as the armature could only turn a certain distance, even if it was not held against the attractive force of the current by the retractive force of the twist in the wire. It is plainly evident that this indicator can be used with systems varying considerably in the potentials required, as a greater or less twist in the wire holding the armature in suspension will require a greater or less force of current to move the pointer to zero. With a scale laid off for the purpose, this indicator would serve as a volt-meter.

Some volt-meters have the scale laid off in degrees or other equal divisions, and each division represents a certain number of volts. When taking readings by such a scale it becomes necessary to multiply the reading by the constant of that particular instrument to get the number of volts.

All of the instruments mentioned so far, are for use with continuous current systems and would not work on alternating currents. The Cardew volt-meter which can be used with either continuous or alternating currents, consists of a circular dial and case, similar in appearance to a steam guage, with a brass tube of about one inch in diameter and two feet long extending from the side of the case. When in use this tube is intended to hang vertically. Within the case is the pinion which carries the pointer and around the pinion is wound a couple of turns of fine wire, one end of which is attached to the free end of a spring in the case and from there, after passing around the arbor, the wire is led through the tube and passes over a roller at the lower end of the tube and up again to the circular case where it terminates at a binding screw which extends to the outside of the case. Opposite to this is another binding screw whose inner end connects with the spring spoken of.

The philosophy of the action of this instrument is that the passage of the current through the wire, which is very small in diameter, and of considerable resistance, as it must be for a volt-meter, sensibly heats the wire and the wire is expanded. The spring in the case, taking up the expansion, rotates the pinion and the pointer is moved across the scale. An instrument of this kind has no magnets or wire coils, and for this reason it can be used close to a dynamo or large mass of iron or steel. There being nothing of a magnetic nature about it and no chance for self-induction, as there are no coils in which self-induction might take place, make this a very convenient instrument for use in places where the machinery is in a limited space, for when there is any iron or steel about an electrical test-

ing instrument it is sure to affect, more or less, the correct working of the instrument and when any of its movable parts are susceptible to magnetism it is certain to be influenced to a greater or less extent by a dynamo or other source of magnetism within a distance of several feet. It is somewhat interesting to take a pocket-compass into the dynamo room and by its use, discover how far the magnetic lines of force extend from the dynamo and you will also discover that every wire carrying a continuous current has a magnetic field about it and the greater the number of amperes passing the stronger the field will be.

There is one feature about some ammeters and volt-meters that is quite convenient and that is that the pointer comes to rest or gives its indications without vibrations. This is called "dead beat." Other instruments not possessing the "dead beat" principle keep up a continual vibratory or oscillating movement of the needle back and forth across the scale, a number of degrees each side of the mark where it should give its indication, and thus make the correct reading of it more or less a matter of guess work.

Instruments for electrical measurement, both volt-meters and ammeters should be constructed in such a manner that they will never need to be recalibrated, but should be constant until some of the parts become very badly worn and even then they should be easily adjusted by some simple means provided in their construction. They should be so constructed that they may be kept continuously in circuit without injury. An ammeter that is intended to be kept continuously in the circuit must have the wires that carry the current large enough to stand any amount of current that they may be required to carry

without heating sufficient to cause any injury to the insulation or change the nature of the wire. A volt-meter should have so high a resistance that but a very small amount of current could pass through it and that portion should not be sufficient to heat the wire perceptibly for if the wire becomes heated its resistance will be increased and less current passing, it cannot give the same indications, though in some instruments, such as the last one described, the expansion of the wire by heat is made the principle of its operation. Ammeters are also made on the same principle though their construction differs considerably from that of the volt-meter described. They should have as little iron or steel in them as possible and without any they would be much better, for when they contain either iron or steel they are sure to be affected more or less by being used near a dynamo. Besides, iron will retain more or less magnetism and the amount retained differs at different times. The magnetic strength of steel also changes. Coils of wire in an instrument of this kind are subject to self-induction and an instrument containing them must be frequently corrected, if they are intended to be absolutely correct; but as there is more or less lee-way allowed in electric lighting it is not necessary to have an extra fine instrument, as a really good one, such as any of those described in these chapters are sufficient for the ordinary purposes of electric lighting.

CHAPTER XVIII.

TESTING.

The importance of frequent testing of dynamos and circuits cannot be over-estimated, for a simple test is sufficient to show a dangerous condition of the line circuit that might, if allowed to remain, cause serious, if not fatal injury to some one; while a test applied to the dynamo may show a defect, that, if not immediately repaired, would result in such injury to the machine as would be quite costly to repair.

There are several kinds of apparatus used for testing that answer the purpose more or less fully and some of them are so simple and cheap that they should be found in every dynamo room, and not only be found there but be put to daily use in testing the condition of circuits and machines.

Perhaps the best apparatus for general testing purposes is the Wheatstone Bridge and Rheostat. Its simplicity and convenience and the ease with which it can be handled makes it a very desirable piece of apparatus to have in an electric light station, but its cost is such that but few of the smaller plants can afford to have it. Another convenient apparatus for a testing set is a galvanometer with two or more cells of battery. The construction of a simple galvanometer has been described in a previous chapter of

this book but we will repeat here that it is a magnetized needle placed over a flat coil of wire; but galvanometers are made in a variety of forms, some of which are explained further on in this chapter. It is connected to the cells of battery by a single wire leading from one of the binding screws of the cell while another wire leads from the other binding screw of the galvanometer, to be used to connect to the circuit or to earth as is most convenient. Another piece of wire is attached to the other binding screw of the battery and is used to complete the circuit.

Before commencing to test the circuit it is better to connect the free ends of the two wires to see that the cells and galvanometer are in good working condition, when, if they are all right the galvanometer needle should show a deflection of about 90 degrees or in other words should move around about one-quarter of the circle. To test the insulation of the circuit: Prepare a good earth connection for one of the free ends of the wire. This earth connection may be made to a steam or water pipe or to any part of the boiler, for the boiler and steam pipes are in connection with the feed pipe and this leads to a good earth—if you are not taking water from a tank.

To prove that you have a good earth connection for one end of your wire, after you have it attached try it by touching the free end of the other wire to the ground or to some pipe that is not connected in any way except through the earth with the first connection. If you get a full deflection of the needle then your earth connection is all right and you can go ahead to test your circuit. The reason for being so particular about your earth connection is that if you do not have good electric contacts there, your

tests would prove nothing for they might indicate high insulation of circuit when it would only be a poor earth connection. After having provided a good earth connection for one of the free ends of the wire take the end of the other wire and make contact to some portion of the circuit—a binding post on the dynamo, for instance, or any part of the circuit. If the needle is deflected it shows that there is a ground on the line or at least a leak and if the deflection is considerable the ground is certainly dangerous and should be traced out at once, and the defect repaired. If, under the test, the needle should show no deflection then you can turn on the current with confidence that there is no danger from that direction.

It is well known that one ground on a circuit can cause no injury but if there is one ground the second is made when anyone touches any portion of the circuit, as a lamp or the brushes of the dynamo or any portion of the circuit through which the current is passing and whoever is brought in contact with the circuit then—unless they be insulated from the ground—will have cause to remember the occurrence. The first ground on a circuit is a dangerous thing. Remove it at once.

If the circuit is carrying a low tension current, of course, the effect on a person would not be very disagreeable but the chance for starting a fire at the place where the circuit is grounded is great enough to make it fully as dangerous as the chance for injury to a person would be with a high tension current.

To trace out a ground with an ordinary detector galvanometer, perhaps as good a way as any is to disconnect the circuit near the dynamo, leaving the ends free from contact with anything and separated from each other,

then go to some distance from the dynamo where the circuit can be easily opened, at a lamp or branch, for instance, open the circuit there and test both sections to the ground by connecting one wire from the galvanometer and cell to the circuit while the other wire from the testing set is connected to ground. The section from which you get a deflection of the galvanometer is the one that is grounded and by following that section and opening it into smaller sections you can readily determine the exact location of the ground, and by carefully insulating at that point the trouble may be easily removed.

In testing for an open circuit, it may be located by disconnecting one wire from the dynamo and grounding the end, then go over the circuit in the same way as when testing for a ground, with the exception that it is not necessary to open the circuit at the places where the test is made but merely to make contact with the circuit, when a deflection of the galvanometer shows the circuit to be continuous so far, while no deflection indicates that the break has been passed.

In testing the field circuit of a dynamo for a ground on the frame, one terminal of the testing set must be brought into contact with the clean iron of the frame, for the paint as well as rust are non-conductors and if not carefully avoided will be the cause of error; the other terminal may be connected to any part of the field circuit. If the galvanometer gives no deflection the insulation may be supposed to be all right, while if the needle is deflected the circuit is certainly grounded to the frame.

Daily test of the armature insulation should be made by testing between the commutator and the shaft. When the armature is connected in close circuit a test

between any portion of the commutator and shaft is sufficient but when the armature is connected in open circuit the test should be made from each segment of the commutator to the shaft and a high resistance galvanometer, with at least three cells of battery, should be used to test the armature of a high potential dynamo. But then, if you should find a leak by such test, the probability is that it would be in a position where you could not get at it to repair it without taking one or more coils of wire off of the armature.

But if you have made the test and found that the armature is leaky and a coil burns out sometime afterward, as it most certainly will, it is some satisfaction to know just why it burned out.

By the use of the simple detector galvanometer, such as we have been describing, many difficulties may be located and the existence of troubles proved. If the galvanometer coils are of low resistance, as they would be if wound with rather coarse wire and of but a few turns, the instrument would then be useful for testing through low resistance only. But the low resistance galvanometer can be put to good use around an electric light plant, and in many tests it is better than a high resistance instrument of the same kind; as for instance, in testing for a break in the armature circuit of a closed circuit armature. In a case of this kind, even if the armature be of the low resistance kind; that is, wound with coarse wire, a break in any of the wires may be detected by testing around the commutator, keeping the terminals of the galvanometer circuit touching segments that lie close together.

In testing in this way you will find that the deflection of the galvanometer needle remains about the same as you

test around, until you strike the segment that is in contact with the broken section, when the galvanometer needle will fall back considerably. If the test just mentioned had been made with a high resistance galvanometer it would have been a very difficult matter to locate the break for, as you understand, the low resistance of the armature circuit, taking all of the wire clear around, would be so very small compared to the resistance of the galvanometer that whether it was added to or taken from the circuit would cause but the slightest variation of the needle, while with a low resistance galvanometer the resistance of the armature circuit would be more nearly equal to the galvanometer circuit, and if both circuits were together in series, the amount of current that could pass would be considerably less, consequently the needle would give less deflection. While testing for an open circuit in the armature, in this way, you will see that while testing around on the closed portion, that there is only the resistance of one section of armature wire added to the resistance of the galvanometer, but as soon as your terminals are on each side of the break then the resistance of the whole armature circuit is added and, of course, the needle drops back a trifle.

The galvanometer is a very useful instrument for testing resistances and is made in a variety of shapes and some of them are wound with both high and low resistance circuits, and sometimes a third circuit of medium resistance is added. An instrument of the kind last mentioned is quite serviceable in any kind of electric testing where comparisons are to be made, or they can be used to determine the number of ohms. In one pattern of galvanometer having three separate circuits and capable of measuring resistances varying from the fraction of an ohm to several thousand

ohms, the circuits are wound in the shape of a hoop in a light frame work of gutta percha or other insulating substance. The first or low resistance circuit consists of a flat strip of copper making one turn around the hoop and connecting to two binding-posts on the base of the instrument. This circuit is of such low resistance that really the resistance of it need not be taken into account. The next circuit consists of a number of turns of insulated wire wound in the same hoop and having a resistance of a few hundred ohms. One terminal of this circuit connects to the same binding post as one end of the first circuit, while the other terminal connects to a separate binding post. The other circuit having an increased resistance, and a greater number of turns of wire are wound on in the same way and connected up in a similar manner. Each circuit is carefully insulated from the others and the circuits altogether form a hoop or ring of square section about one inch in thickness and several inches in diameter. This ring is attached to the base in such a way that it will be in a verticle position when the instrument is in use. The magnetized needle is about $\frac{7}{8}$ inch long, but it carries a pointer, made of alluminum or some light, non-magnetic metal several inches long. This needle is suspended exactly in the center of the ring and may be poised on a needle point or suspended by a fiber of untwisted silk. In what ever way the needle may be held in position, the object is to have it as free to move as is possible. When resting on a point, the point should be of hardened steel and the bearing in the needle should be a jewel. This will insure the smallest amount of friction and allow great freedom of movement. With the scale laid off in degrees and tangents this instrument can be made to cover a very wide

range of measurements. In making tests by the tangent galvanometer it is necessary to have a table of tangents to refer to, for you will understand from what has been explained in a former chapter of this book, that if a given strength of current gives a deflection of a certain number of degrees, doubling the current strength does not give double the amount of deflection, but something less than that amount. For a current that would give a deflection of 15 degrees, if doubled would only give a deflection of about 28 degrees and this is considerable less than twice as much. And the greater the first deflection is the more difference you will find, for if the first deflection should

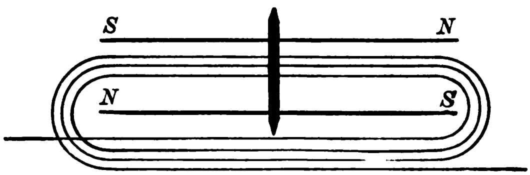


Fig. 61.

be 35 degrees, doubling the strength of current would give but 54.5 degrees; but with a table of tangents handy or with a tangent scale, comparisons are easily made.

There are several ways of increasing the sensitiveness of a galvanometer. One way is by increasing the effective action of the current on the needle by using a greater number of turns of wire in the coil, for no matter how small the amount of current passing, each turn of wire that it passes through adds just that much to the effect it has on the needle. Another way to increase the sensitiveness is to make the needle astatic. An astatic needle is shown in Fig. 61, where two magnetized needles are placed

on one arbor, one of the needles insi .e of the coil, while the other is outside, but the needles also have their poles pointing in opposite directions, or in other words the *N* end of one needle points in the same direction as the *S* end of the other needle. By arranging them in this way two points are gained by which their sensitiveness is increased. With the poles pointing in opposite directions the earth's magnetism has less influence over them, for the magnetism of both needles is so nearly alike, that there is just enough difference to keep them in a position pointing north and south. So, with the effectiveness of the earth's magnetism reduced to the lowest practical amount, and the magnetism of the needles as great as they can contain, the current in the coil will exert its greatest power over the needles, and as there is but slight resistance to their movement, a very small amount of current will cause the needles to swing through a greater number of degrees than if a single needle alone was used. Another point about this arrangement is that, although the two needles have their poles acting in opposite direotions, you will notice that the effect of the current through the coil will act on both needles to turn them in the same direction. This also gives increased effect. Another way in which the sensitiveness of the galvanometer is increased is by lengthening the pointer. This is done without greatly increasing the weight, by placing a small mirror on the needle, and reflecting a beam of light from it on to a scale placed a couple of feet away. The light is obtained from a lamp placed in a convenient position and partially shaded so that the light is thrown only on the mirror. This is the most sensitive galvanometer known. It is called the Thomson reflecting galvanometer.

The "Differential" galvanometer is an interesting instru-

ment, and its peculiarity is that it has a double coil, that is, there are two coils placed on the same plane and the needle is pivoted between. This would give two separate circuits of the same number of turns and of the same resistance. This is necessary, for the circuits are to be connected in such a way that the current will divide and pass through them in opposite directions—one neutralizing the other's influence on the needle, so that when the current is passed through the coils the needle will not move. In connection with the differential galvanometer a rheostat or series of coils of known resistance is used. The rheostat is connected in the circuit of one of the galvanometer coils, and the object to be tested is connected into the circuit of the other coil. If the resistance in each coil is the same, then an equal amount of current will pass through each coil, and there will be no change in the position of the needle ; but if the resistance in the two coils be different, then the greater portion of the current will pass through that coil having the least resistance, and the needle will be influenced accordingly. Now, by varying the resistance, by the use of the rheostat, the needle can be brought to zero again. When this is done, it is evident that the resistance in each coil is equal, and by reading the resistance from the rheostat the exact resistance of the object is known. Some galvanometers having a very great number of turns of wire will, with one cell of battery, give a deflection through a resistance of one million ohms. Any of the principles described above may be applied to a galvanometer of any convenient pattern.

CHAPTER XIX.

THE WHEATSTONE BRIDGE.

Perhaps the most convenient and compact testing set and one that is reliable and has a very wide range of usefulness is the so-called Wheatstone bridge. It is in reality an electric balance or differential arrangement. The Wheatstone bridge was devised in the year 1833, by a man named Christie. This gives some idea of the state of electrical knowledge at that time, and when people speak of electricity being in its infancy it really appears that the infantile part of it, is in their minds. When an instrument having the wide range and precision found in this differential arrangement becomes a necessity in the electrical art, it would appear that the infantile stage had been passed.

A description of the principles of the instrument may be more easily understood from a few diagrams. Fig. 62 shows the theoretical arrangement of the differential system. Here we have four wires arranged in a diamond or lozenge shape shown by *A*, *B*, *C*, *D*. From the junction of *A* and *C* at *3* a wire leads to the opposite side at *4*. In this wire a galvanometer *G*, is connected. At the points *1* and *2* are connected the terminals of a battery shown at *E*. In three of the branches are introduced resistance coils, shown by the small black circles, those in the branch *C* being a rheostat of various resistances. The resistances are con-

nected to brass strips after the style of the rheostats already described in these chapters. The connections between the strips are made with brass plugs, slightly tapered and ground to a fit, for it is necessary that they make a good firm contact and to insure this it is best to always give the plugs a slight twist when putting them in place. To use the arrangement as shown in this diagram, we would connect the object that we wished to measure the resistance of, into the circuit *D*.

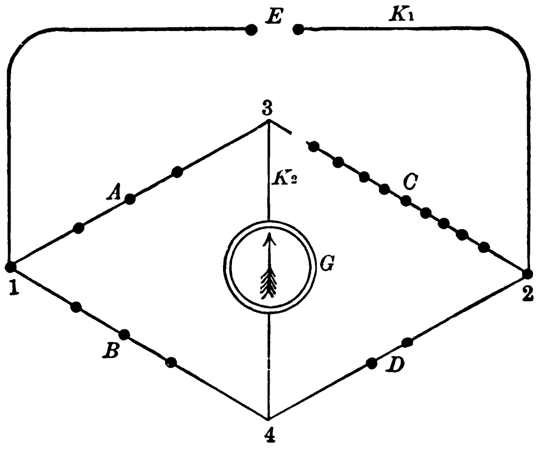


Figure 62.

The current from the battery *E* entering at *1*, has two paths open for it, through *A* and *B*, and if they be of equal resistance, as we will assume they are, for the present, divides there and flows equally through each branch to *3* and *4*. Now if the resistance of *D* is greater than the resistance unplugged in *C*, a portion of the current will flow from *4* through the galvanometer circuit across to *3* and from

there the reunited current passes through C to 2 and from there returns to the battery. Now when a portion of the current flows through the galvanometer the needle will show it by being deflected to one side. If we introduce more resistance into C by removing some of the plugs, we will find that the needle is brought to zero as soon as the resistance in C is equal to the resistance at D, for then the current from the battery flows equally through A, C, and B, D, and under these conditions no current can flow across through the galvanometer. When the galvanometer needle is at rest on the zero mark the exact resistance of the object at D is found by determining the amount of resistance unplugged in C and as the resistance is plainly marked opposite each hole it is easily read off.

In cases where the resistance of the object is equalled by the whole or any portion of the resistances in the rheostat at C it is quite easy to get at the resistance of the object. But suppose the object to be measured has a greater resistance than the whole of the rheostat at C then we would have to unplug a greater amount of resistance in B than we have unplugged in C. Suppose in A there was 10 ohms and in B there should be 100 ohms unplugged that would give a ratio of 10 to one. Then if we had to unplug twenty-five hundred ohms in C to get a balance to bring the galvanometer needle to zero, then we should know that the resistance of the object at C is ten times twenty-five hundred or 25,000 ohms, for if B is ten times as great as A, then D or the object to be measured must have a resistance ten times greater than the resistance unplugged in C.

If the branches A and B each have three different resistances, say of one, ten, and one hundred ohms, then if one

be unplugged in *A* and one hundred in *B* it is evident that a resistance one hundred times as great as is contained in the rheostat *C* may be measured at *D*, and also if 100 is unplugged in *A* and one in *B* then an object of one one-hundredth part the resistance in *C* may be measured equally well. In the four sides of the Wheatstone bridge arrangement you will find that the resistances bear the same relation to each other in several different ways, for when *A* bears a certain relation to *B* it will be found that *C* bears a similar relation to *D*. We also find that as *A* is to *C* so is *B* to *D*. Again we find that if *B* is multiplied by *C* it will equal *A* multiplied by *D*. You will find that these parts always bear certain relations to each other even when calculated in the different ways, and it is well worth the time required to make yourself familiar with at least one way of calculating the record of the bridge, for if you never expect to use it yourself you may want to know, sometime, that it is being correctly read off. A formula may assist you in remembering the different ways in which the resistance may be calculated from the bridge, and this is the way it is laid down in my memoranda.

$$A:C::B:D. \quad A:B::C:D. \quad A \times D = B \times C.$$

It is read in this way: As *A* is to *C* so is *B* to *D*; again, as *A* is to *B* so is *C* to *D*; and again, $A \times D = B \times C$. It is well to remember these, for bridges on this same principle are made in a variety of shapes, but they can nearly all be read from this formula.

There are two forms in which the bridge and rheostat are usually found, and the connections of each are shown in the following diagrams. Fig. 63 shows the round form and how its connections are arranged. In this diagram the two heavy lines show the two branches *A* and *B*, and

are marked with these letters: the circuit *C* containing twenty-four resistances, ranging from the small amount of one one-hundredths of an ohm, to one of four thousand ohms. The branches *A* and *B* each contain, in this diagram, three sets of resistance of one, ten and one hundred ohms, giving the set a range from one one-hundredth of

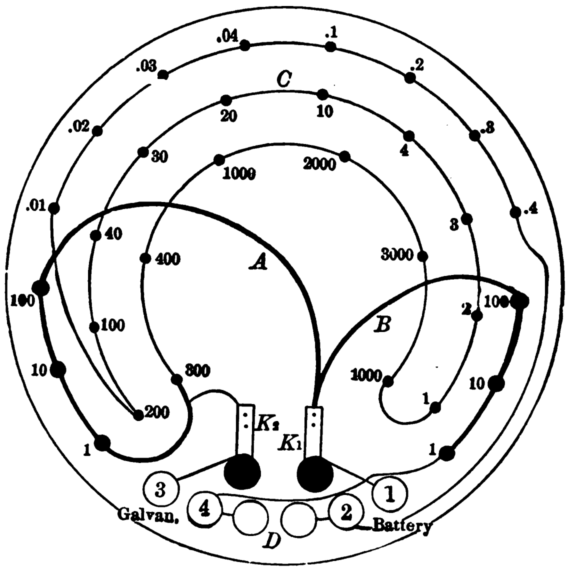


Figure 63.

the smallest or one ten-thousandths of an ohm—useful for measuring the sections of armature wire in low resistance armatures or short pieces of wire—up to one hundred times the resistance of the largest coil, or four hundred thousand ohms. The six small circles on the diagram represent binding posts, and the ones marked *1* and *2* are for the battery connections and correspond to the same num-

bers in Fig. 62, as do all the other letters and numbers. The two binding posts at the left, marked *3* and *4* are the galvanometer connections, and any good galvanometer may be used with this instrument. The other binding posts at D are for connecting the object to be tested, and this letter also corresponds to the same in Fig. 62. There are two keys, shown at K^1, K^2, the location of which are also shown in Fig. 62, where you will see that one of them is in the battery circuit, and the other, K^2, is in the galvanometer branch. These keys are quite important, although they have not been mentioned before, for when testing, if an open circuit battery such as the Leclanche is used, it would run down or lose its force if kept on closed circuit for any length of time, while by having the key in the circuit the circuit is open except when the key is pressed down. The other key, in the galvanometer circuit serves to protect the wire of the galvanometer coil from the heating effect of too heavy currents when several cells of battery are used, for you know that high resistance galvanometers, such as are usually used with these instruments, are of very fine wire, and too much current through it would injure it by overheating.

A rheostat and bridge of this kind is a very perplexing thing to look at while you do not understand what is inside of it, but when you understand just what it contains and, in your imagination, can see it all and trace out the connections and locate them, why, then it becomes quite simple and is very easy to use.

Another form of bridge, called the Post-Office pattern, from its having been adopted by the English post-office department, is shown in Fig. 64. This is in square form but the arrangements and connections are just the same

as shown in the two previous diagrams, but this apparatus has the galvanometer in the same box, and it is made a portion of the instrument. There is also a plug in this instrument marked *Inf.* that when removed opens the circuit in the *C* branch and, if no deflection of the needle then occurs, the resistance in the *D* or *X* branch will be infinite. The abbreviation means infinity, or practically, more resistance than the instrument can measure. You will notice

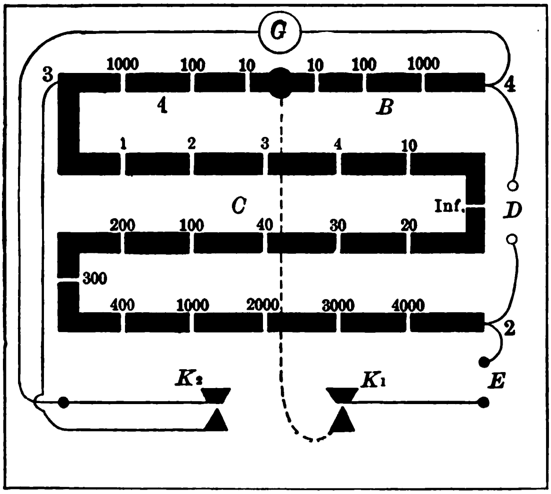


Figure 64.

that this instrument will not measure as low a resistance as the other just described, for it has not those coils, the resistance of which is in decimal parts of an ohm. But it has fully as high a range, although the resistances are somewhat different.

All of these instruments described above will be found of great usefulness around an electric light station, and if

used occasionally will be found far more reliable than any amount of guess-work, even when made by a very proficient guesser.

The magnetos which are frequently used for certain kinds of testing are more or less of an assistance in guess-work and serves a purpose, although quite a limited one, and may be of considerable use around an electric lighting plant if used in connection with more or less knowledge. In the next chapter the principles and construction of the magneto, and several ways in which it may be used to advantage are described.

CHAPTER XX.

THE MAGNETO AS A TESTING INSTRUMENT.

The apparatus called a magneto, and frequently used for testing around electric machinery, is a very convenient instrument, as far as it goes, but it is not by any means a real testing apparatus. The magneto is in reality an alternating current generator with a permanent magnet, instead of electro-magnet for exciting the field. This arrangement

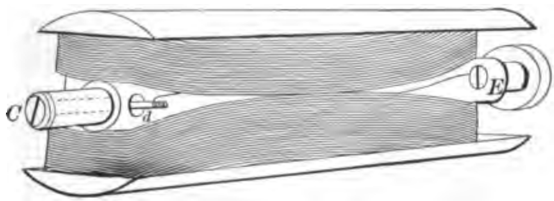


Figure 65.

does not, of course, give near the strength of field that an electro-magnet would, but an electro-magnet could not be charged by an alternating current. We can expect but little from the magneto when using it for testing, because it was not designed for such a purpose. The original purpose for which it was brought into use, in its present shape, was merely to ring a bell, to call attention on a telephone line. This it usually does to perfection, even when the line

is about forty miles long, and of number 14 iron wire. This line would have a resistance of about two thousand ohms. But as the strength of current developed by magnetos varies more or less in the different instruments, it is well, when buying one, to try its strength and get one as strong as possible. In some of the magnetos the magnet

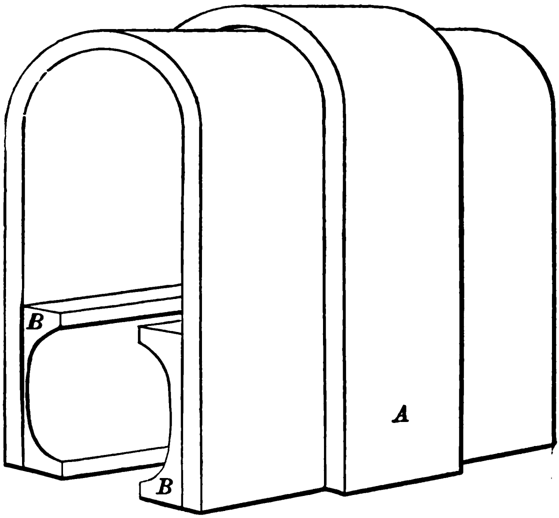


Fig. 66.

is made of a single piece of steel about a quarter of an inch thick and three to three and a half inches wide, bent into U shape. In others three or more magnets of the same shape, but narrower, are placed together, as shown in Fig. 66, to form a compound magnet; for two or more magnets placed together in this way make a magnet of greater strength than a single piece containing the same weight of

material. Compound magnets are built up in many different ways with the object of increasing their strength, but in a magneto it is doubtful if it is of any particular value; for some magnetos with a single magnet prove to be of greater strength, or rather will ring a bell through greater resistance, than some others of the compound kind. But in either case the magnets are of hardened steel, about as hard as they can be made without being brittle. They can be magnetized by contact with the pole pieces of a dynamo, which is, perhaps, the most convenient way, as it saturates them in a moment. Some care is necessary to get both poles at about the same strength and of opposite polarity, although if a special arrangement is used, less care is necessary, and a moment's contact is sufficient to saturate them.

The pole pieces shown at *B* are of cast iron, fitted inside of the magnet and bored true to admit the armature. End pieces of brass that carry the armature shaft are fitted to the bore of the pole pieces and serve to keep the magnet from springing, which otherwise might grip the armature and prevent its turning, but in this way it makes the whole thing quite solid. The armature is of the Siemens' H form, and shown in Fig. 65. It is made of cast iron, and wound with cotton or silk insulated wire of about number thirty-four. Four ounces of wire is the average amount used on each armature. One end of the shaft, as you will notice in the cut at *C* to *d*, is bored into far enough to bring the end of the hole inside of the bearing; this hole is fitted with a hard rubber bushing which is threaded inside for a screw. This screw, *C*, forms one terminal of the armature circuit, and is insulated from the shaft by the hard rubber bushing. Inside the bearing a

hole is bored through the shaft, and a smaller hole through the hard rubber. Through this hole is a short piece of copper wire of about number sixteen, held in place by the screw, *C*, with which it makes electrical contact, while both are insulated from the shaft and core. One end of the armature wire is fastened to this piece of wire by a drop of solder. This is shown at *d*. An alternate current generator needs no commutator, for the whole electric impulse is first in one direction over the circuit, and then in the opposite direction.

The armature winding is in two sections, and is continuous, filling first one half of the armature, and then across and filling the other half, and is wound in the same directions on each half. The other end of the wire is attached to the core, as shown at *E*, and is, consequently, in electrical connection with the magnets and all parts of the framework. The arrangement for turning the armature varies in the different kinds of magneto. In some a gear and pinion is used, while in others grooved pulleys and a rubber band serve the purpose.

The bell used in connection with the magneto has some points of interest about it, and is quite simple when fully understood. Two spools of wire with iron cores fastened to a yoke piece form an ordinary electro-magnet, but the armature of this magnet is somewhat different from that of an ordinary electro-magnet used with continuous currents, and but a few years ago considerable ingenuity was required to make a bell that would ring by an alternating current. Several ways were devised by which it could be done, and other ways might have been brought out if it had been necessary. But a polarized armature overcame the difficulties, and perhaps as

good a way as any in which this was applied is shown in Fig. 67, where *M*, *M*, are the spools, and *N*, *N*, the pole pieces, which are extended toward each other, with one end of the polarized armature, *n*, *s*, between.

This armature has a brass wire extension with a ball on its end that taps the bells as the armature is attracted first to one side then to the other, as the current is passed

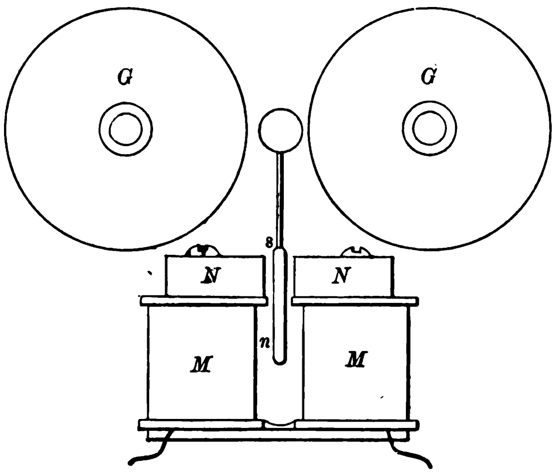


Fig. 67.

through the magnets in each direction. There are several other arrangements by which the bell is made to ring by an alternating current; but as the alternating magneto has some characteristics about it that will prevent it from ever becoming a reliable testing instrument it will be unnecessary to illustrate them. The magneto, as at present constructed, is simply a generator of electricity of a medium high tension. Just how many volts it will generate depends upon the number of turns of wire in the arma-

ture and how fast it is revolved, as well as upon the strength of the magnet. As the current it produces is not commutated, it of course goes to the line or circuit in alternations. With the bell in the circuit, and not too much other resistance, enough current can be generated to ring the bell. If there is too much resistance the bell will not ring, and there you are. The use of the magneto to test with is just one little notch ahead of a cell of battery and a simple electric bell. Either will ring through a circuit if there is not too much resistance in the circuit. But the magneto is, perhaps, the most convenient instrument of the two, as it will ring through a resistance that would require a specially wound bell and a battery of several cells to give the same indications. The magneto will give a very strong current, comparatively, even when that current is not strong enough to ring the bell. To get a very good idea of the strength of current it will give before the bell will ring; take hold of the wires leading from the binding posts—a wire in each hand—and let some friend turn the crank. If he is one of the "cranks" that are always trying to be funny, he will turn quite fast at the start and by this means you can judge quite closely as to the amount of current that might leak from a circuit even if it had so much resistance that a magneto would not ring a bell through it.

There is no such thing as a perfect insulator of electricity any more than there is an insulator of magnetism. It is all a question of resistance. The more resistance, the better the insulation. If you do have to rely on the magneto for doing your testing around the plant, when you are testing circuit insulation, and the bell doesn't ring between circuit and ground, then put yourself in circuit

with the magneto and try it again. This can be done by taking the end of one wire, that leads from the magneto, between your thumb and finger and placing the fingers of the other hand upon some uninsulated part of the circuit and then, with the other wire from the magneto well grounded, try it again. If you cannot feel any current, when testing in this way, the circuit is fairly well insulated. But hold on. Your fingers are dry. Wet them and try it again, for you know that some substances, when dry, are very good insulators, while if they are damp, they are better conductors. If you can feel no current with your moistened fingers then touch the end of the wire to your tongue while the moistened fingers are in contact with some portion of the circuit, and try the magneto again. If no current can be felt, when testing in this way, then you may be confident that the circuit is as well insulated as is necessary in any plant where the engineer is his own electrician.

There are cases, in testing circuit resistance, where the magneto is said to give a false ring; but as this would be an error on the safe side no particular harm would be done. The case in which a false ring might be given, is where the circuit is extensive enough to have sufficient static capacity to condense electricity enough within itself to react on the magneto and cause the bell to ring. Just how much of a condenser it would require to produce this false alarm would depend, to a great extent, upon the kind of magneto used. To find a condenser in the electric light business large enough to produce this effect, we will have to look among the lead-covered cables and find one of considerable length before we will get the static capacity necessary to give us this false alarm, and even then the

static charge would not produce a continuous ring of the bell.

In testing for circuit in the field coils of a shunt wound dynamo of large size it is possible that the shunt circuit might be of so great resistance that the magneto bell would not ring through the whole circuit. In such a case, if you should find it, you can try a part of the circuit at a time. Shunt field circuits of so high a resistance would probably have a rheostat connected in, and, if near the middle of the circuit, from there the test could be made each way to the terminals of the circuit; so there would be no difficulty in getting around that. In using the magneto in a circuit where the conditions are favorable to self-inductions and extra currents, it would be quite easy to be misled. But as the magneto was never designed as a test instrument, and has no appliance whatever for measuring resistance or anything else, and has nothing to calibrate, and if it had it would not be reliable, in the cases mentioned above, so long as it gave an alternating current, or could be bought for so small a price. It is a very convenient little instrument for anything within its capacity, as it is easily handled (or would be if the manufacturers would put a handle on it to carry it by) and is always ready, not requiring any tedious or exact preparation; has no solution to be cared for or spilled, no glass to break, and, taken altogether, in the absence of any more elaborate and complicate and costly apparatus, it is well worth its cost around an electric light plant. If more is wanted than the magneto will give, more money will have to be paid for it.

The diagram, Fig. 68, shows the circuits outside of the armature, with the lightning arrester, the cut-out and the

contact pieces. In the diagram *A*, is the magnet, *c* is one terminal of the armature circuit where the screw makes contact with the brass clip. This is a moving contact, but requires no particular attention. From here the circuit goes to the binding post *P*, from there to the line, but from the binding post a branch goes to the lightning arrester *L*. This lightning arrester is simply two pieces of brass, one of them toothed like a saw, for it is believed that lightning prefers a point to jump on or from, rather than a smooth surface; but it is a fact that static electricity will escape from a point, or be drawn to a pointed conductor in preference to a smoother surface.

When a magneto is used on a telephone wire, or for signaling to a distance, a ground wire is run from one binding post, and in case of lightning on the line this arrester helps to protect the armature and bell coils from being injured by it By referring to the diagram you will see that the binding post at the right is the one that should be grounded. Another branch runs from the lightning arrester to the gear wheel *S*, and makes contact at the flat spring *h*. This is for the purpose of cutting the generator out of action, when the magneto is used as a call on a telephone line. When the magneto is to be used, this short circuit is broken by pushing in on the handle *K*, while it is being turned; this moves the gear away from the spring, but does not interfere with its working, for the pinion *s* is long enough to still engage the teeth. On some other magnetos a push button is used for the same purpose. From the other binding post there is also a branch to the lightning arrester, but the circuit goes to the contact spring *q*. This would be on the side of the box which contains the generator, near the hinges, and makes

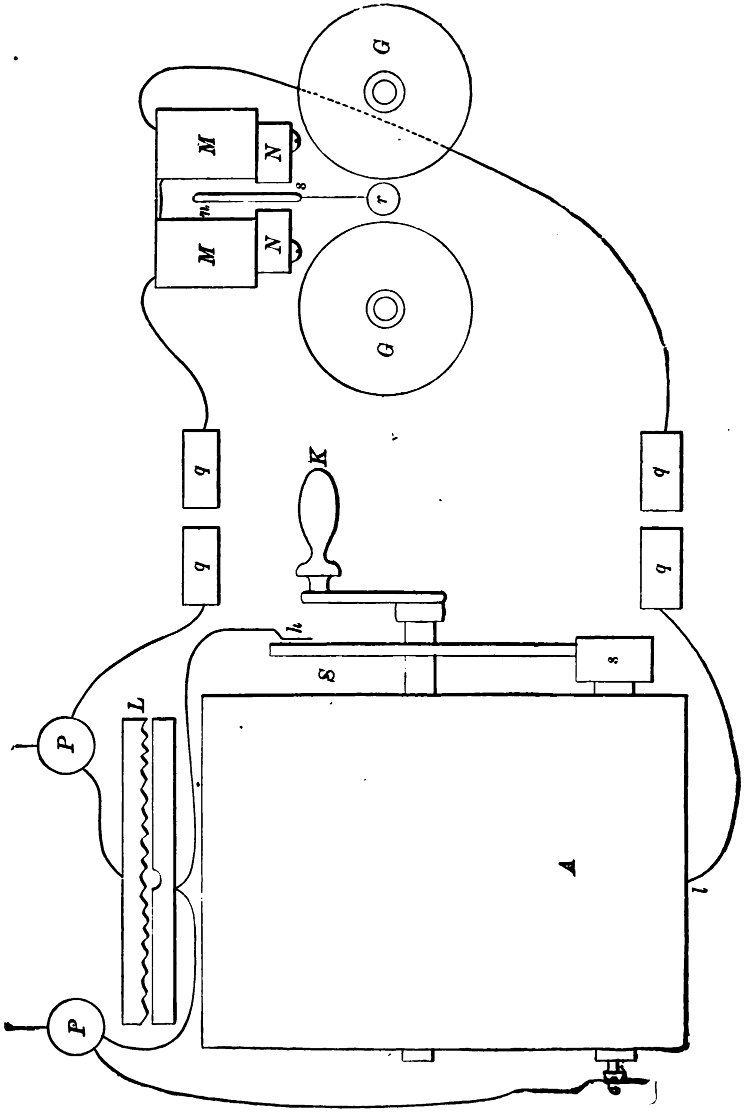


Fig. 68.

contact with the other spring when the lid, carrying the bell, is closed. Some machines make this part of the circuit through the hinges. As the current enters the spools and magnetizes the cores and the pole-pieces, one having *N* and the other *S* magnetism, the armature being polarized, is attracted to one side and repulsed by the other pole-piece; but at the next electrical impulse, which is in the opposite direction, the polarity of the pole-pieces change, but as the polarity of the armature remains the same it is attracted to the other side. The continued alternating impulses of current continuously changing the polarity of the pole-pieces keeps the pivoted armature in a continuous vibration, and the little ball on the extension keeps tapping first one bell and then the other with no break in the circuit. The return from the spools, as shown, is through two other springs that are in contact when the lid is closed, and from there to the pole-piece of the magnet at *l*, and through the frame-work and bearings to the armature shaft and the armature wire at *e*, Fig. 65. The magneto shows the principles of one style of alternating current, machine. Perhaps we may at some future time investigate the principles and trace out the circuits of some of the alternating dynamos and motors and reason a little about their peculiar actions.

Speaking of condensers and static capacity—there is frequently a dynamo so well insulated from the floor that it becomes a condenser of the electricity produced by the friction of the belt. If the belt is dry and runs free between the pulleys, that is, if there is nothing nearer to the belt than some portion of the dynamo, then the frictional electricity will be discharged from the belt into the frame of the dynamo, which will act as a condenser, and

the static charge will become so great that there will be potential sufficient to cause the electricity to jump some little distance—from half an inch to an inch—through the air. This is frequently noticed when the hand or an oil can is brought near any portion of the dynamo. A little spark appears to jump from the hand, or the oil can, as the case may be, a sharp snap is heard, and a stinging sensation is felt; then it is all over, the greater part of the charge has escaped, and the condenser contains only a small charge, of low potential. Several sparks may be drawn from the frame of a dynamo that has condensed a static charge in this manner, if care is taken to draw the first spark from as great a distance as it will strike through, and each succeeding spark from a lesser distance each time. If the dynamo is only fairly well insulated from the ground, the spark will jump only a short distance; but if thoroughly insulated and everything around is quite dry, a spark will often jump between a person and the dynamo with such force and noise as to be quite a surprise. Sometimes the static charge will become so great, especially if plenty of time has been allowed it to gather, that it will discharge through the insulation to the armature or field circuit. When this has been allowed to occur the insulation at that point—perhaps no larger than the point of a pin—is weakened, and the next accumulation of the static charge finds an easier path at the same point.

When static electricity—which means electricity in a state of rest—is discharged through an insulator it makes a small hole, sometimes smaller than could be made with a needle, and it is probable that a slight charring or carbonizing takes place. At any rate, there is an easier escape for the next charge through the same place, and it

becomes easier and easier for each successive charge, until, after a time, the dynamo current finds its way through the same place, and a burnt armature or leaky field is the result. A mysterious case of burnt armatures occurred three times in one dynamo, and the cause was found to be static electricity from the belt had found a condenser in the dynamo frame, and its easiest way of escape was through the insulation to the armature wire, and then the dynamo current jumped through at the same place. Their trouble with burnt armatures was cured by connecting the frame to ground with a small wire.

Their method was not the best, as their wire formed a ground connection between the frame and earth, and being of small resistance, was ready at all times to make trouble as soon as the next ground occurred. Perhaps a better plan would have been to have connected a wire to a good ground and brought the end to within a half-inch or so of the belt. This would have taken all of the frictional electricity from the belt before it had acquired a potential sufficient to have been noticed. This method of dealing with static electricity has been found to work well in all cases where the requirements were complied with. In one case where a printing press was seemingly bewitched, as the paper after having passed through the press and on to the long wooden fingers that were supposed to lay the sheets nicely in place, refused to be laid with the neatness expected of them and many sailed away in an aggravating manner; the cause of the trouble was static electricity. The weather was dry and the fingers of the machine had been sandpapered and varnished—well insulated—and the press was standing on a very dry floor. You will notice that the conditions were favorable for condensation. In this case

temporary relief was obtained by sprinkling the floor around the press, and a permanent cure was effected with a few pieces of wire.

Electricity generated through friction between dry belts and air, is something that will cause trouble in more places than a dynamo room, and should never be allowed to accumulate in a condenser, for it is quite easy to divert it before it becomes troublesome, and around electric light machines or motors it is capable of causing considerable damage.

CHAPTER XXI.

COUPLING DYNAMOS TOGETHER.

Dynamos are freqently coupled together on constant current as well as on constant potential circuits. An arc light, constant current circuit of considerable length may have been established and the demand for lights may have increased faster and to a greater number than had been anticipated. Under these circumstances the dynamo would soon be overloaded and it would be necessary to build another circuit or add another dynamo to the circuit already in use. The latter plan is frequently adopted. For series lighting we have series wound and shunt wound dynamos. Either of these may be coupled up in series and cut into or out of circuit as may be required. In constant current circuits the size of the wire is large enough for any addition that may be made to the work on the line, for the current is limited, in the first place, to a certain number of amperes. Any addition to the work to be done will require more e. m. f. but the number of amperes on the circuit will remain the same. On a multiple, or constant potential circuit, the size of wire is usually determined for the greatest load that it will ever be required to carry.

On constant potential circuits an overload is a greater number of amperes than the wire is capable of carrying

without heating to a dangerous degree. When more than one dynamo is used on a circuit of this kind, the size of the wire sufficient to carry the full amount of current that it may be called on to supply, has been calculated at the start, and no greater amount should ever be thrown upon it without first increasing its capacity by larger feeders, mains and branches, or by adding other wires. For supplying constant potential circuits, series, shunt and com-

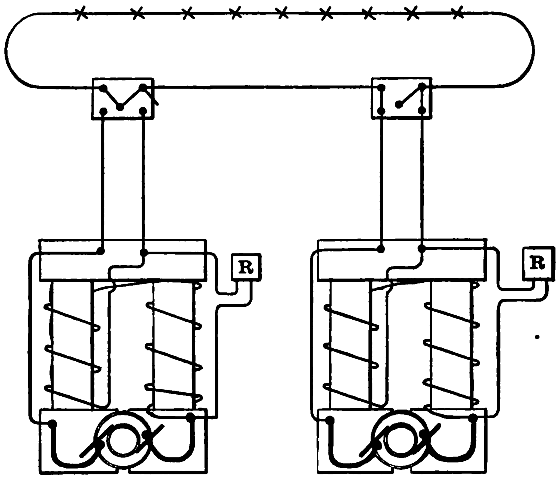


Fig. 69.

pound wound dynamos are in use. Either style of these machines may be coupled together in multiple or parallel, and can be thrown into or out of circuit as required. The following sketches show the connections required with the different kinds of machines. Certain precautions are necessary, in the different cases, to prevent trouble, but with care there is no particular difficulty in cutting in or out of a dynamo.

With series dynamos on a series system, coupling together is easily accomplished. Many series dynamos have a system of automatic regulation, and when two or more of these are coupled together it is the usual practice to throw out of action the regulators of all but one of the dynamos, requiring this one to do the regulating. The diagram, Fig. 69, shows how the connections are made, together with the 3-point switch that throws the dynamo on open circuit when cut out. The dynamos shown refer to no particular make or type of dynamo nor any particular system or regulation, although a shunt resistance between the field terminals is shown. When a circuit is in operation, and the load increases until it becomes necessary to throw in another dynamo, it is only required to get the dynamo up to speed, with the belt tight enough not to slip when it takes the load, and then close the switch. This continues the circuit through the machine just thrown in, the magnets become energised, and the current produced in the armature is added to the line. If the machines have automatic regulators it is the usual practice to throw the regulator of one machine out of action, allowing that machine to work at full load while the other dynamo does the regulating. When a machine is thrown in, in this way, there is a momentary fall of the current, due to the resistance of the second dynamo, but this lasts only two or three seconds, until the machine is fully in action. This method works very well in practice. In some plants it is customary to short circuit the dynamo for an instant before it is thrown into circuit. By short circuiting for an instant, the dynamo is allowed to get fully in action before it is switched in. This will prevent the slight fall of current on the line, but instead, it throws a great potential into the

circuit which continues until the regulator has time to act. Either of these ways are quite practical and depend, to a certain extent, upon the kind of switches or switch board in use and considerably upon the person who handles the switches.

To switch out, it is only necessary to slow down the dynamo, short circuit the field, and switch the machine out.

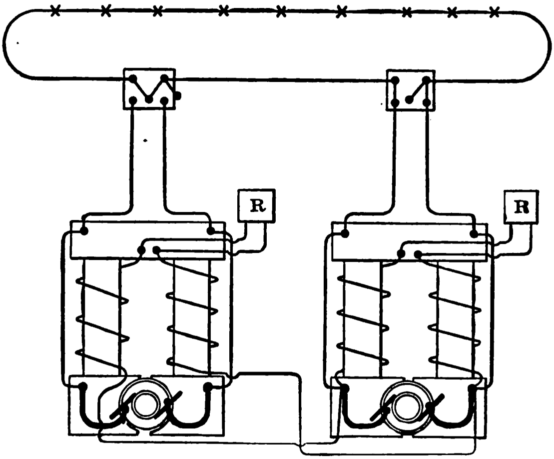


Fig. 70.

When shunt dynamos are to be connected in series, it becomes necessary to make some changes in the field circuit connections, for if the dynamos should be simply connected in series, the current from one dynamo would reverse the polarity of the field of the second. This will readily be seen by tracing the path that the current would take through the field of the second dynamo, if the machines were thrown together without any special arrangement. See Fig. 70.

But the machines will work together all right by connecting the field circuit of the second dynamo in parallel with the field circuit of the first. This method will allow the magnets of both dynamos to be excited in the same manner, by the current generated by the first machine. Two or more dynamos may be connected in this way, having their fields excited by the first, and any of them but the first, may be thrown into or out of circuit at any time, while current is on the line.

With this arrangement a dynamo may be thrown into circuit by first connecting the field circuit of the second machine to the circuit of the first dynamo as shown, and then switching the armature into circuit. To cut out a dynamo, the field circuit should be first disconnected to demagnetize the field and stop the generation of current. The armature may then be thrown on open circuit.

Another way in which two shunt machines may be connected up in series is by connecting the fields of both machines together in series. This will work all right if the combined resistance of the two field circuits is not too great to allow of the magnets becoming fully charged, but as there is usually a rheostat in the field circuit of all shunt wound machines, this can be regulated as required.

For throwing machines into and out of a series circuit the 3-point switch is a very convenient arrangement. With any of the standard switch boards in use the changes can easily be made.

Series wound, constant potential dynamos may be coupled in multiple or parallel by making a slight change in the arrangement of the field circuit. If simply connected in parallel, one machine would be almost certain to reverse the polarity of the other, for should the e. m. f. of

one machine become reduced from any cause, the other machine would overpower it and change its polarity. Just how this would occur can be readily seen from an examination of the diagram, Fig. 71. This difficulty is easily overcome by connecting corresponding terminals of the field circuits together by a large wire, as shown by the dotted line. This wire serves to keep the fields of both machines charged alike.

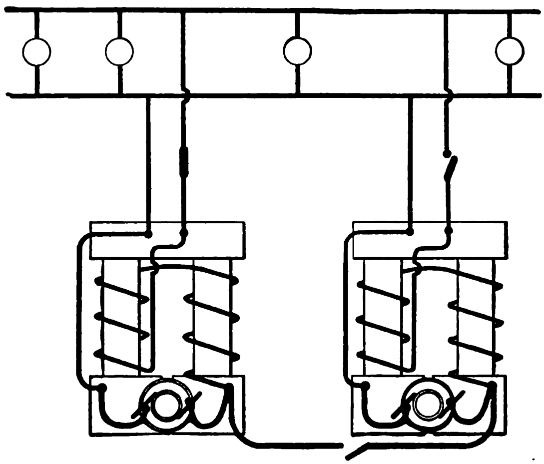


Fig. 71.

With this arrangement, to switch a machine into the circuit the machine should be up to speed and generating, which can be seen by the pilot lamp connected across between the brushes. As soon as the lamp is up to candle-power, make the connection by the cross-wire, and then switch into circuit. To cut the machine out of circuit it should be first disconnected from the main, then open the switch in the wire between the machines. The dynamo

can then be stopped. With machines in multiple it is only necessary to open one main to throw them out of circuit.

Shunt machines to any number can be connected in multiple without difficulty, and no trouble is experienced in switching in or out of circuit at any time. Shunt machines, when connected in multiple, if one or more of them are to be thrown out or in at any time during the

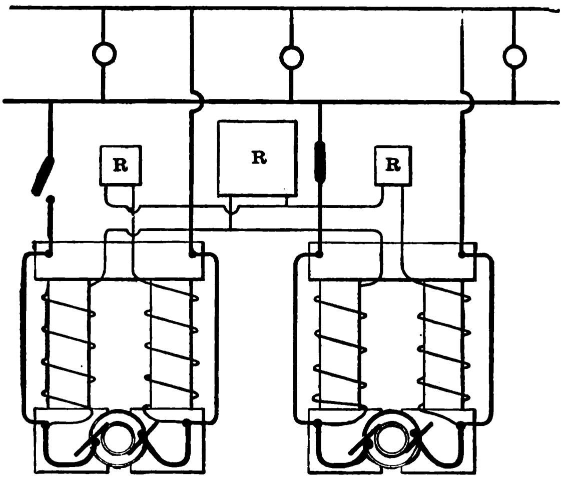


Fig. 72.

run, are usually regulated by the rheostat connected to each machine, with the object of causing each machine to produce its part of the whole work. Sometimes an extra rheostat or regulator is connected up in such a way as to regulate all of the dynamos at once. The regulator of each dynamo is set so that each machine is doing its share of the work, and this extra regulator which is connected with the other rheostat serves to regulate the whole num-

ber of dynamos at once. This may be arranged, as shown in Fig. 72, by connecting one end of the break in the field circuit of each machine to the regulator of that particular machine (the same terminal of each field circuit must be connected to the regulator); the other wire leading from the regulators is connected to one binding post of the extra regulator, while the other terminal from each of the field circuits is connected to the other binding post of the extra regulator. In this way several shunt dynamos in multiple, working on one circuit, may be regulated by a single rheostat, and work extremely well in practice.

The only precautions necessary in throwing shunt machines together in multiple, is that the machine be running and up to potential before it is switched in. Shunt dynamos usually require a few seconds' time to become fully magnetized, and gather their full potential after the field circuit is closed, even when up to speed. Some means is required to show when the machine is up to its potential, for if it be switched in before it is generating sufficient potential, the pressure from the mains being so much greater would overpower the dynamo about to be switched in, and cause it to act as a motor. Should this occur the belt would fly of, or the armature burn out. There are several arrangements for telling when the dynamo is up to potential. One way is by noticing the pilot lamp, which on some machines is attached to a socket on the headboard, and on other dynamos is placed between the feeders near the dynamo and inside of the switch If this arrangement is used the potential is adjusted by the regulator until the pilot lamp is up to the same candle-power as the other lamps. The switch can then be closed. If the potential of both dynamos is exactly the same at

the instant of closing the switch, the lamps will show no indications of any change having been made; but as it is a difficult matter to judge by the eye alone that the lamps are at exactly the same candle-power, there is usually a slight change noticed when a machine is switched in. To prevent this change in lamps and to tell when the machines are at exactly the same potential, a galvanometer has been connected between the negative wire of the dynamo (for that is the one the switch is in) and the negative wires in the mains. When this arrangement is in use it is easy to tell by it when the potential of the dynamo and the potential in the mains is equal, for there will be no current through the galvanometer and it will stand at zero. The dynamo may then be switched in without affecting the lamps. Where dynamos are worked in multiple each should have an ampere meter in the circuit between the dynamo and mains. One potential indicator, connected at center of distribution, is all that is neccessary for any number of dynamos feeding the same circuit. When a dynamo is to be cut out of circuit, throw resistance into its field by the rheostat until the ammeter shows that no current is passing from the dynamos, then open the switch. In preparing to cut out a dynamo in this way, it will be found that all of the resistance need not be thrown into the field circuit to cut the current down to zero; but when the ammeter marks zero the dynamo may be switched out without a spark at the switch, while if too much resistance be thrown into the field the potential will fall until current from the mains will be forced through the armature in the opposite direction, making an accident possible.

With compound wound dynamos connected in parallel the case is somewhat more complicated, although the

principal is about the same as with series wound dynamos connected in multiple. Compound wound dynamos, at present, are only used for constant potential circuits, and some of them are absolutely automatic in regulation, while the others require more or less regulating. The terminals of the shunt fields are always, practically, connected to opposite brushes, and lead from there around the magnets,

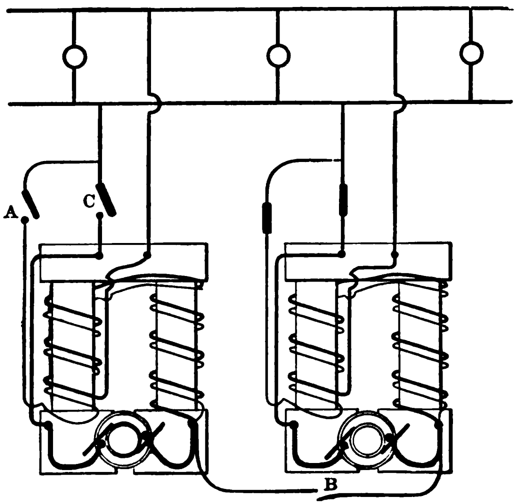


Fig. 73.

while the series winding leads from one brush around the magnets and from there to the circuit before returning to the other brush. As this has been fully explained in a previous chapter it is not necessary that it be repeated here. There are different ways of constructing compound wound dynamos; in one case the series winding magnetizes and the shunt acts to demagnetize; in another, both windings magnetize, or in other words, in one case

the windings act together, while in another they oppose each other. But in coupling compound wound dynamos together, the same arrangement will answer for either kind, for the series portion of the winding must be connected in the same manner as is shown with the series dynamos in multiple in Fig. 71, while the shunt windings are connected in parallel, the same as the field windings of the shunt machines working in multiple, as shown in Fig. 72. Somewhat different management is required with compound wound machines when switching them into or out of circuit with other machines. A diagram of the connections and switches required is shown in Fig. 73, but a compound switch may be constructed that will require but a single movement of the handle to make the different connections in the order required. In the shunt circuit of each dynamo a switch is required to open that circuit, and the shunt terminal should be outside of the switch that closes the series circuit, for it is necessary to close the shunt circuit first, when about to switch in a compound wound machine. Referring to the diagram we find a switch in the shunt circuit *A*, another in the circuit of the series winding *C*, and one in the connecting wire *B*, between similar brushes of the different machines. The connecting wire, *B*, is required to prevent one machine from forcing current through the other, as it would do if the e. m. f. of the second dynamo should, from any cause, fall a few volts. With this connecting wire placed between similar brushes, the current passing through the fields of both machines must be equal at all times. Several dynamos of this kind may be coupled together after this manner and no difficulty need be experienced in their operation.

To start the first dynamo it is only necessary to have the switches in the shunt and series circuit closed with the brushes in position and get the dynamo up to speed, when it will generate and give the required potential. To throw in the second machine, get up to speed, put the brushes in position, close the shunt circuit by the switch *A*, next close the circuit through *B*, then finish by closing *C*. To cut out a machine the switches are to be opened in the reverse order from which they were closed; that is, open *C* first, then *B*, then *A*; this cuts the machine out of circuit completely.

CHAPTER XXII.

SWITCHES AND SWITCH-BOARDS.

In any electric light plant, among the important fixtures are the switches, and it is just as important to have good switches, as to have any other part of the apparatus good. A switch, whether used for low tension or high tension currents should have large contact surfaces and the design should be such as will allow of the surfaces making firm contact without too much friction. It is best to have a switch work with such freedom that it will never stick and cause delay, for many times a moment's delay in the opening or closing of a switch may result in serious injury to persons or machines. A switch that requires to be fastened with a screw to insure good contact, should be avoided as being an element of danger. A switch that makes a sliding contact on one side of the levers only is to be avoided as unreliable, for such contacts usually give trouble, and where a switch of this kind is carrying current it will generally be found quite warm, proving that the contact is poor and that there is considerable resistance at that point. A reliable and serviceable switch, one that can be depended on, should have not only large contact surfaces but contacts should be made on both sides of the lever or of the lug with which the lever engages, and there should be sufficient spring or flexibility to allow of

a wedge-like action when the parts are brought together. There are several ways of constructing a switch to fulfill these requirements. The lever may be made of two strips separated by about ⅛″ space and engaging with a lug cast on the binding post. This makes excellent contact by the pressure derived from the spring of the metal, and the sliding of the parts keeps the contacts clean and reduces the resistance so that they seldom heat to any appreciable extent. Another style of switch has a solid lever cut from sheet metal of a width and thickness sufficient to give the strength and rigidity as well as the carrying capacity required, and is arranged to make contact by sliding between a solid base and a spring, which insures good contact over a large surface. For incandescent lighting circuits the switches should be large enough to carry, without heating at the contacts, any current required on the circuit to which they are attached, for with low potential currents any resistance sufficient to produce heat will cause a fall of the potential and reduce the candle power of the lamps.

In parallel circuits it is the usual practice to open but one side of the circuit in cutting out a loop or throwing off work and for this purpose a single pole switch is sufficient, while on series circuits the switch should be capable of closing the main circuit and cutting the loop free at both sides and doing it without a spark at any of the contacts about the switch. For this purpose a double pole switch is necessary and it must be arranged so that the main circuit is closed before the loop is opened. A double pole switch of either of the styles described will answer all the requirements if provided with an extra contact point connected to the opposite binding post in the main circuit, as

shown in Fig. 74. With this style of switch the loop can be cut out, leaving no part in connection with the main circuit. The lever will make connection with the short circuiting contact before opening the circuit at any point, consequently there will be no spark at any of the contacts when the loop is disconnected. It is preferable to have all parts of switches used in high potential circuits so

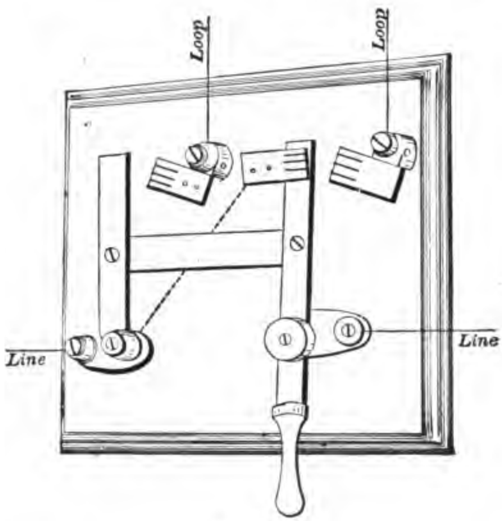


Fig. 74.

covered and insulated that it is impossible to touch any of the parts through which current is passing. Accidents about electrical machinery are only possible when well known requirements are ignored or overlooked. Where several circuits or several machines are in use a switch-board becomes a necessity, for it is always safer and much more convenient to handle the circuits from one point

than to have the switches located in different parts of a room. A switch-board is more serviceable and convenient when set at such a distance from the wall as will allow of plenty of room back of it, so that a person can get behind it to work and make connections when necessary without danger of coming in contact with any "live" points. Where room is limited a switch-board may be fastened by hinges so that it may be swung close to the wall to get it out of the way as much as possible and still allow of readily changing the connections. By swinging it outward it will permit of getting at the back to do any work that may become necessary. With parallel systems a single point switch is all that is required, and any of the

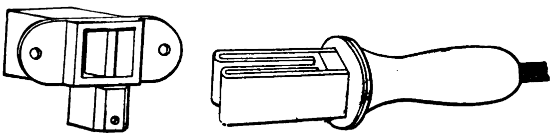


Fig. 75.

styles described will answer the purpose if heavy enough to carry the current. On switch-boards of this kind where a number of circuits branch off, one wire only of the circuit is led to the switch-board and connected to the switch. Each switch should be labeled in a manner that will show at a glance which circuit it controls, so that there need be no hesitation when called on to cut out a circuit. In lighting stations where there are a number of dynamos and a greater number of circuits, a switch-board is an absolute necessity, and the many different contrivances that were brought out for this purpose before anything really safe and practical was obtained would form quite an interesting collection. The apparatus now most exten-

sively in use and which has given the greatest satisfaction, is the plug and socket.

There are several styles of these plugs and sockets, one of which is shown in Fig. 75. In this arrangement the plug is formed of sheet metal, bent several times in such a manner as to form a square plug as shown. The socket is of cast brass, having a square opening divided to a certain distance by a partition that forms two other sides with which the plug, when inserted, makes contact. The plug by being made of sheet metal and bent into the shape shown, gives four sides that make contact with the socket. This ensures plenty of bearing surface and the spring of the metal in the plug insures friction enough to hold it reasonably secure in the socket. With the plug and socket arrangement the sockets should be placed in the board in such a way that no part of them will project beyond the face of the board and in this way avoiding all chance of the operator coming in contact with any metal that may form a part of the circuit. The socket shown in Fig 75, is designed to be attached by screws to the face of the board, leaving a large portion of the metal exposed, and for this reason alone this style of socket should never be used with high potential circuits. The plug and socket shown in Fig. 76, consists of a round plug with the end rounded off so that it may be more easily inserted into the socket. In the socket is a spring which engages with a notch on the plug and serves to hold the plug in place. The spring also assists in making a good electrical contact. To remove the plug it is necessary to give it a quarter turn, which releases it from the spring. The lower hole in this socket and the tapering plug are for the purpose of making changes between dynamos and circuits without at

any time opening a circuit. The tapering plug is not intended to remain in the socket longer than for a second or two at a time and for this reason is made tapering with no provision for holding it secure. This style of socket is secured to the back of the board and the projection through which the hole for the plug is drilled, as shown in the diagram, enters, but does not project quite through a hole bored through the face of the switch-board. This arrangement removes from the face of the switch-board all metal parts and makes it well nigh impossible to come in

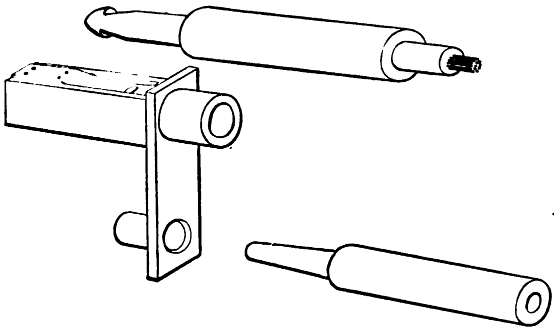


Fig. 76.

contact with any portion through which a current is passing. The smaller hole in the socket casting is entirely behind the board and is not a source of danger. The plugs are connected by pieces of well-insulated cable wires, long enough to allow the plugs to be inserted at any part of the switch-board. The cable wires are soldered into holes drilled in one end of each plug and the wooden handle covering the cable is screwed on to the plug, effectually insulating all parts except that portion required for making contact in the sockets.

Another style of plug and socket for switch-boards is shown in Fig. 77. This arrangement is clearly shown in the cut, and may be described as consisting of two slotted tubes, placed one above the other, and held rigidly in place by the casting to which they are attached. The farther end of the tube is slightly contracted to form a catch that enters the grove near the end of the plug and holds it secure when the plug is in place and offers but slight resistance when the plug is to be withdrawn. This socket is designed to be attached to the back of the board

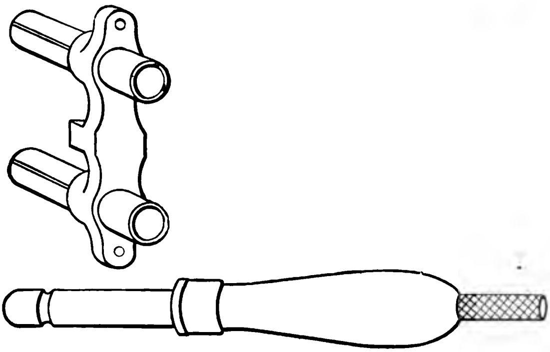


Fig. 77.

leaving no part exposed, so that accidental contacts are almost impossible and safety is assured while changing connections on the board.

CHAPTER XXIII.

ELECTRIC MOTORS.

In general form and appearance an electric motor is the same as a dynamo, and it is a fact that a good motor must possess the same characteristics as those required in a good dynamo. Any dynamo can be operated as a motor when supplied with proper current from an outside source. The duties required of electric motors are so varied that a single type is not capable of meeting all the demands. A motor that would be suitable for continuous working at a constant speed under a load that would suddenly and frequently vary from nearly or quite that of its full capacity to perhaps so small a load that it would represent only the friction of the machine itself would be suitable only for certain classes of work, while for other kinds of work a motor would be required that would be available for operation under various changes of both load and speed, and it is evident that a single motor comprising such elements of simplicity and efficiency as are characteristic of modern machinery could not possess such general utility as would make them suitable for work under such widely varying conditions. Two types of motors have been found capable of fulfilling nearly all the requirements of practice. For constant speed work the simple shunt-wound motor is all that is required, for when constructed in a suitable manner and supplied with current under a constant potential, it will maintain a practically constant speed under all changes of

load within its capacity, and even when slightly overloaded the variation of speed will be no greater than that produced in automatic engines under similar conditions. A change of load on an automatic engine must of necessity produce a slight change of speed, and while the same is true of a shunt-wound motor, the change is not nearly so great as in the case of the automatic engine. In a shunt-wound dynamo, where the field circuit is in shunt or parallel with the armature, the current with which they are supplied is divided between them in accordance with their respective resistances, the circuit having the greatest resistance receiving the least amount of current, and vice versa. In designing the field circuit of a shunt-wound motor, the same attention must be given to the number of ampere turns in the coils and the resistance of the circuit, that is required in the field circuit of a similar type of dynamo, for while a given number of ampere turns are required to charge the magnets to the required degree of saturation, the resistance must be such that no more than the reqired amount of current can flow in that direction. It is equally important that the resistance of the circuit should not be too great, for in such case the magnets could not become fully charged, and consequently the power of the motor would not be as great as might be conveniently obtained from that size of machine. With a known number of ampere turns required to charge the magnets to the desired degree of saturation, it is evident that the resistance of the field circuit must be in accordance with the potential of the current used to operate the motor, for it is evident that if the resistance of the field circuit had been calculated for a potential of 100 volts, and an attempt was made to use it on a 220 volt circuit,

more than twice the calculated amount of current would pass through the field circuit, with the probable result that the wires would become heated to such an extent that the insulation would be instantly destroyed. On the other hand, if the resistance of the circuit had been calculated for a high potential current and the motor was placed in a circuit of lower potential, one result would be that the magnets, on account of the high resistance of the field circuit, would not become charged sufficiently to permit of much power being developed. A shunt-wound or constant potential motor must be constructed with due regard for the potential of the current by which it is to be operated, as it cannot be operated with satisfactory results on any other. The resistance of the field circuit must be proportioned to the potential of the current with which it is to be used, and the number of turns in the coils must be calculated so that the number of amperes flowing through the number of turns of conductor will be just sufficient to produce the required number of lines of force in the pole pieces. These calculations should be made with exactness, as too high a degree of magnetization would be wasteful on account of consuming energy that could not be utilized in the production of useful work, while if the magnets were not sufficiently charged, the power developed by the machine would be below the capacity at which it might be economically operated, and there would be a lot of material serving no purpose.

The armature of a shunt-wound motor may be the same in every respect as that of a series or compound wound machine. But as the amount of current which flows through the armature circuit determines, to a great extent, the amount of power developed, the armature cir-

cuit is made of quite low resistance. Being of low resistance there is nothing to prevent an almost unlimited number of amperes of current flowing through the armature if some resistance is not interposed which will prevent it. But certain characteristics of the machine prevent any abnormal flow when it is in operation and running at or near its critical speed.

The direction of revolution of a motor is opposite to what it would be if operated as a dynamo and producing current, the flow of which would be in the same direction as that employed to operate it as a motor, so that when the armature is revolved in one direction by the action of the current an E. M. F. tending to flow in the opposite direction is produced in the armature and opposes the E. M. F. of the exciting current, tending to obstruct its flow, and operating in very nearly the same manner as an ordinary resistance coil would. The production of this counter E. M. F. may be understood by considering that in order to make a dynamo operate as a motor and have the same direction of revolution as when acting as a generator, the direction of flow of the current through either the magnets or the armature must be reversed, while in the case of a series motor the direction of flow of the current through both magnets and armature must be reversed. This is easily accomplished by changing the lead wires in the binding posts forming the terminals of the machine. The way this will operate to cause the motor to revolve in the same direction as the generator may be gathered from the diagrams Figs. 78, 79 and 80, where the circuit of a series generator is shown in Fig. 78. It is evident that, if current was caused to flow in the opposite direction through the armature and field circuit of such a machine,

the direction of rotation would also be in the opposite direction, for the polarity of the armature would be reversed, and in such case the current would flow through the armature instead of being generated in the armature. While acting as a generator the polarities of the armature and of the pole pieces are so opposed that force is required to move them apart, while in the case of

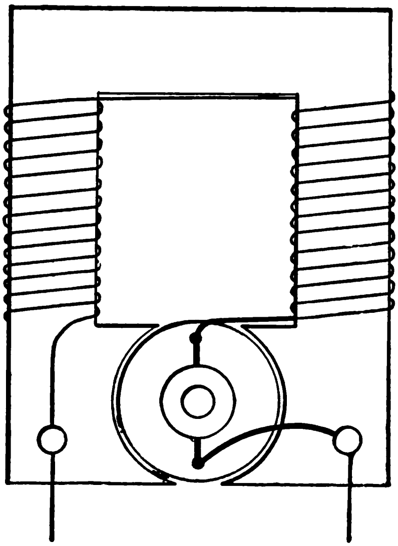


Fig. 78.—Series Winding.

a motor the attraction between the armature and pole pieces on the one hand and the repulsion between the armature and the pole pieces on the other combine to cause the armature to revolve. Supposing a shunt-wound generator to be used in charging a storage battery and by accident the driving belt should come off, the return of the current would flow through the armature in a direc-

tion opposite to what it did while the machine was being driven, but the direction of flow through the field coils would remain the same, thus providing the conditions necessary for the operation of the motor in the same direction. That this would be the case is plainly shown by the diagram Fig. 79, where the arrow points show the

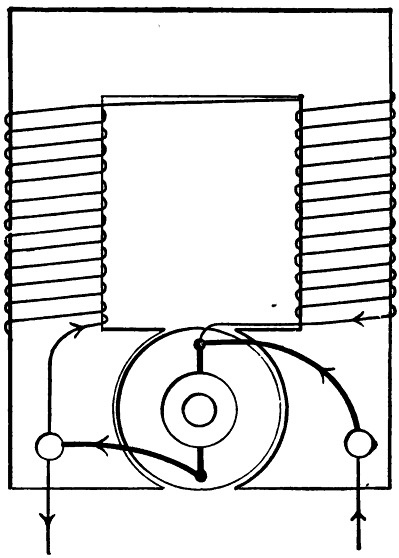


Fig. 79.—Shunt Winding.

direction of the current while the machine is being operated as a generator. It is shown that the current produced by the armature as it leaves the brushes divides, a portion flowing through the fields and the balance to the external circuit, the amount passing in either direction being inversely proportional to the resistance of the circuit. As the field circuit of a shunt-wound machine is always of

very high resistance, for reasons given in previous chapters, the amount of current passing in this direction is very small compared with that which goes to the line. While a motor is thus being driven by current from an outside source, the machine will also act as a generator on account of the fields being charged and the armature being driven. The E. M. F. thus produced being in opposition to that of the exciting currents it retards the flow to such an extent that, when the motor is running light, the two opposing electro-motive forces are so nearly balanced that the flow of current through the armature is only sufficient to provide power enough to overcome the friction of the machine. When work is thrown on the motor, the speed of the armature is slackened somewhat, and as a consequence the counter E. M. F. is reduced, and more current flows through the armature developing more power. This trifling reduction of the speed is in no way detrimental, as the variation is but slight, and in a well constructed motor the variation for all loads will not exceed three per cent. and for nearly all purposes this can be considered as perfect regulation.

A compound-wound motor is capable of giving absolutely perfect regulation, but the necessity for any closer regulation of speed than that given by the shunt-wound machine is not required, except in extremely few cases. A shunt-wound dynamo would not be so efficient if used as a motor, on account of the resistance of the field circuit being somewhat less, for when used as a generator the current builds up very slowly, the resistance of the field circuit being so great that the magnets are but slowly charged. When a shunt-wound machine is used as a motor, the magnets become fully charged so soon as the

current is turned on, for the exciting current is then at the full potential. In starting a motor of any kind, especially a shunt-wound machine, it is necessary that the current to the armature be turned on slowly, permitting the armature to attain a high rate of speed before the current is all applied. The reasons for this will be understood by considering what has been mentioned before, that the armature is of low resistance, and if the full force of the current was suddenly applied the flow through the armature would be so great as to destroy the insulation and cause a burn out. To avoid this the current must be slowly applied, allowing the armature to attain sufficient speed to produce a counter electro-motive force that will prevent the flow of a surplus of current. Another reason for supplying the current to the armature in a slowly increasing quantity is, that if suddenly applied in full strength, even when the motor is connected to a constant current circuit where there would be no such danger of a burn out, the strain on the armature, from the suddenly produced torque, would be so great that the armature wires would possibly be loosened, which, if it should occur, would lead to its speedy destruction. To avoid the danger of a burn out, or other injury to the motor when starting, a series of resistance coils are connected in the armature circuit, and so arranged that the flow of current can be gradually increased as the speed of the armature increases. This arrangement requires that there be three wires leading to the motor, as shown in Fig. 80, which also shows the manner in which the circuits and resistances are arranged, so that when the switch is closed the field coils are thrown into circuit and the magnets charged. When the lever of the starting box is in this position no current

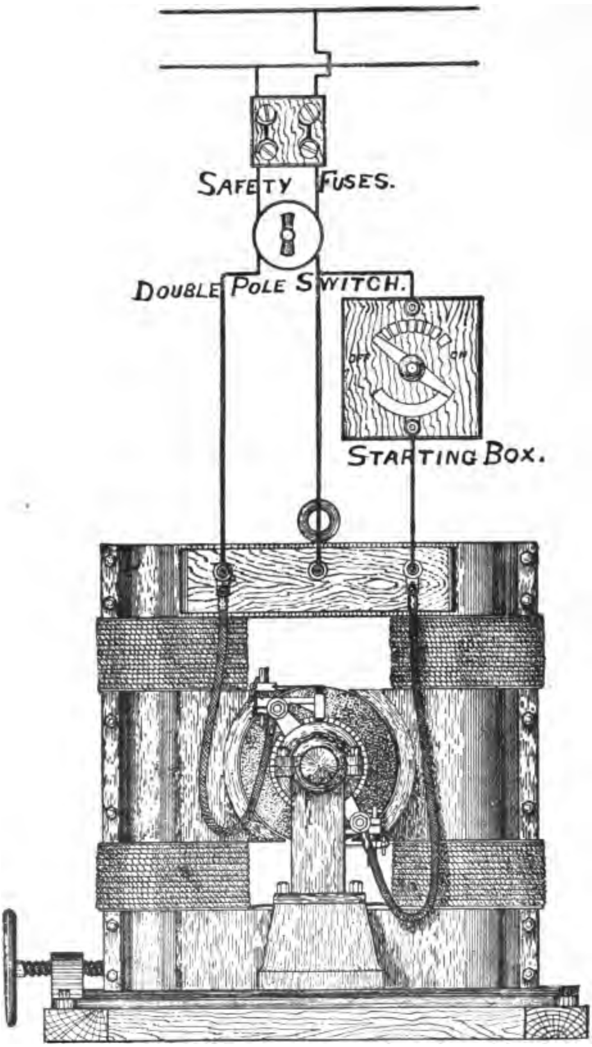


Fig. 80.—Shunt Motor, Connections and Starting Box.

is passing through the armature, but by moving the lever to the next segment a portion of the current, regulated by the resistance coils, passes through the armature. This puts the armature in motion, and the lever is moved to the next segment which, by reducing the resistance, permits a greater volume of current to flow through the armature, and the speed is further increased. As the speed increases more resistance is thrown out until the motor is fully up to speed and all the current turned on, after which the motor will care for itself, so far as the supply of current is concerned. But should the supply of current be interrupted from any cause, so that the motor would stop, or nearly stop, it would be necessary to then throw in some of the resistance to protect the armature, for when the full flow of the current was re-established the counter E. M. F. would not be sufficient to prevent injury to the armature.

When it is required to control the speed of a shunt-wound motor, it may be accomplished by the use of a variable resistance connected in the field circuit, which acts by changing the intensity of the poles, and consequently varying the power of the motor. This method of regulation would not alone be applicable to a motor receiving current from a constant potential circuit, for, as the speed of the armature was reduced, the flow of current in this direction would be increased, and might become so great as to injure the armature. When used on a constant current circuit the plan would work all right, as only a given amount of current could then flow through the armature, and this amount would be limited, so that no injury would occur from over heating. The shunt-wound motor is particularly suited for constant speed

work on constant potential circuits, for under such conditions, it is, as we have seen, practically self-regulating and constant.

For constant speed work on constant current or arc light circuits, the series motor is more particularly adapted, and numerous machines are in use which are operated in this manner, but the subject of regulation then becomes more complicated. There are a number of motors of this kind that employ a system of regulation that works fully as well in practice as do shunt motors under the conditions previously explained. In most of these motors the regulation is obtained by varying the magnetism of the field through some change produced in the number of ampere turns in the field coils. The Excelsior motor is one of this class, the field coils being wound and connected in the same manner as in the Excelsior arc dynamo, the changes in the field being produced in the same manner, with the exception that in the motor the cut-out lever is actuated by a small fly-ball governor instead of a small motor, as in the dynamo. The method of the winding and the manner in which the cut-out lever is utilized to vary the number of turns in the field coils is shown in Fig. 42. There is another make of motors that employs a similar method of cutting out turns in the field coils. Another means employed for practically the same purpose, is by the use of a shunt of variable resistance across the field, similar in its operation to the method of regulation employed in the Brush arc dynamo, as shown in Fig. 33, and fully explained in the same connection. As applied in the motor referred to, a fly-ball, or centrifugal governor, is employed to operate the variable resistance. Another method of series motor

regulation consists of changing the position of the brushes on the commutator, the yoke being moved by the governor. A plan similar in its effects to the last one mentioned is that employed in the Brush motor, where, instead of moving the brushes, the commutator is rotated on the shaft, which, practically, produces the effect of changing the point of commutation, which also varies the power developed, and results in maintaining the speed constant.

The rotation of the commutator in this case is produced by the action of a tangential governor, something after the style of those employed for producing the regulation on some of the high speed engines. There are other plans by which the series motor may be automatically regulated to preserve a constant speed under changing loads, but the most practicable ones have been mentioned.

When motors are used for work which requires that the speed be changeable, some system of hand regulation is employed, which operates by varying the magnetic effects of the field upon the armature, such as by changing the number of turns in the field, or varying the flow of current through the field circuit, or by the use of a variable resistance in shunt with armature and field; by rocking the brushes; moving the magnets away from the armature, as is provided for in one motor, or by moving the armature out of the field, as is designed in two other types of motors. Hand regulation is also used in the handling of street railway motors, and the explanations already given will apply equally well to this class of machines.

The care of a motor is precisely similar to that of a

dynamo in every respect where the machines are the same. The only particular difference being that the carbon brush is now used almost exclusively on motors, and is fast coming into use on dynamos. The term "brush" hardly applies to the form of the carbon collector employed, as it consists of a thin block of carbon of about the same texture as that used for arc light carbons. When this kind of collector is used, the brush holder usually consists of a short, square tube, so arranged that the end of the carbon plate is presented to the commutator, and is held in firm contact by a flat spring which presses against the outer end of the carbon plate. Another form of carbon collector is made to take the place of the copper brushes, commonly used on dynamos, and consists of a somewhat thicker block than the kind just described. By the use of carbon brushes, the wear of the commutator is very greatly lessened, it being almost imperceptible. This results from the carbon block being much softer than the copper in the segments. When copper brushes are used, if the ends be softened, they will wear the commutator less, and give better results in other ways than the harder material. In starting a motor, especially of the shunt-wound type, the current should be turned on slowly until the armature gets into motion, then more resistance should be thrown out, and as the speed increases, still more resistance must be cut out until by the time the armature is up to speed there should be none of the resistance left in the armature circuit. Never attempt to regulate the speed of a shunt machine, designed for working at constant speed, by the starting box, for although it can, to some extent, be done, it is not advisable to attempt it, as it may result in heating the resistance and causing injury. In stopping

a motor of this kind, do not attempt to do so by slowing down gradually, as this might also cause damage in a manner similar to that just mentioned, but shut the current off instantly by the lever on the starting box—**never** by the line switch; but after the motor has been stopped by the use of the starting box lever, then, if necessary, open the line switch. If the supply of current should be shut off from the motor at any time, it will be necessary to close the starting switch to prevent injury to the armature of the machine when the current is again turned on. The reason for this will be understood by remembering that when the armature is standing still there is nothing to prevent an enormous flow of current through the armature circuit, but when the armature is in motion and the fields charged, then the counter E. M. F. produced acts as a resistance and prevents the flow of too great a current. This counter E. M. F. is in proportion to the speed, and only attains its full value when the armature is at its rated speed. By knowing this fact, and turning on the current according to the speed attained, there is no danger of any injury resulting from too much current, but if the load on the motor should become so great as to slow down the armature, the counter E. M. F. would be reduced so much that the flow of current might, and probably would, be so great as to cause a burn out.

A series motor on any circuit should also be started carefully, not so much on account of any danger of a burn out, as on account of the strain on the armature wire from the sudden jerk that would be given to it if the full force of the current should be suddenly applied. To sum up in a few words: Start slow, and give a motor the same care and attention that you would a dynamo.

CONCLUSION.

In closing this series of chapters it may be proper to say that the original plan contemplated a description and explanation of the various machines and apparatus used in an electric light plant, the care and management of which come particularly within the province of the engineer. It is believed that this plan has been well followed out and that no omissions of any great importance have been made. If it were attempted to go fully into the theory of electricity and electrical machinery the work could be prolonged indefinitely. Enough practical information has been given, however, to enable any engineer who will take the trouble to master what has been written in these articles to take charge of an electric light or power plant and manage it successfully.

At the risk of repetition it may be well to again call attention to the more important points connected with the electrical part of the plant which the engineer should always bear carefully in mind. Keep the circuits in good order, the lines well secured, the insulation resistance as high as possible. Keep the dynamos clean and well insulated from the foundation. Pay particular attention to the commutator and brushes. Keep the commutator smooth and the brushes in good order and making contact with the commutator at the right points. Keep all parts of arc lamps clean and working free, for the least friction about the mechanism or stickiness of the rods will impair its working and a poor light will be the result. Have an ammeter on the circuit, if it is a continuous current circuit, or a volt-meter on a constant potential circuit, for without these, even with a system of automatic regulation, troubles will occur that will be difficult to locate, but with

them best results can be maintained. Have some kind of testing instrument that is reliable and make frequent use of it. A magneto is not altogether reliable and does not measure anything, but it is better than no testing apparatus at all. Whatever system of regulation you may have should be kept in the best of order, for it is only when in that condition that it is reliable and with the descriptions that have been given of automatic regulators there should be no difficulty in understanding them and keeping them in order. And finally, when indications of trouble are discovered, remedy it THEN.

If the foregoing explanations of electrical principles and the descriptions of apparatus are read attentively and applied in practice there is no engineer who need have any serious difficulty with any system of electric light machinery

ELECTRICITY FOR ENGINEERS,

PART II.

ALTERNATE CURRENT APPARATUS.

J. H. YEWDALE & SONS CO.,
ELECTROTYPERS, PRINTERS AND BINDERS,
MILWAUKEE, WIS.

ALTERNATE

CURRENT APPARATUS,

BEING

PART II

OF

ELECTRICITY FOR ENGINEERS.

CONTAINING AN EXPLANATION OF THE PRINCIPLES GOVERNING THE GENERATION OF, AND A DESCRIPTION OF THE INSTRUMENTS AND MACHINERY USED IN CONNECTION WITH ALTERNATE ELECTRICAL CURRENTS.

BY CHARLES DESMOND.

CHICAGO:
JOHN ROBERTS & CO.,
1894.

Copyright, 1894,
By John Roberts.

CONTENTS.

Page.

CHAPTER VII.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

CHAPTER XIII.

CHAPTER XIV.

CHAPTER XV.

Page.

CHAPTER XVI.

CHAPTER XVII.

CHAPTER XVIII.

CHAPTER XIX.

ALTERNATE CURRENT APPARATUS.

INTRODUCTORY.

The success which has attended the applications of the inductive system of incandescent electric lighting by alternate currents in this country as well as in others, and the late successful adaptation of the same system to arc lamps, indicate that it is to be the system of the future for central station lighting. And the indications are that all the purposes to which the continuous electric current has been so successfully applied will, in the near future, be as successfully operated by either direct or induced alternate currents. Although the alternate current system was the first to be applied to the production of electric lighting on a commercial scale, it did not become a success, as it was soon supplanted by the continuous current system. The principal reason for this was that the characteristics of continuous currents were better understood at that time, on account of nearly all the previous investigations having been made with battery currents which were continuous and steady. The investigations made with these currents had so nearly covered the field of their application that the principles and laws as laid down in the text books of forty years ago, will be found sufficient to explain nearly all of the applications of the continuous current of the present day. All of the electrical formulæ for continuous currents in use at the present time are deduced from the researches of Faraday, concluded about the year 1831, or

from laws demonstrated by others about that time. But the laws of alternating currents had not been investigated until within the last few years, and the only reason for the lack of success in the commercial use of them in the past has been a lack of knowledge of their characteristics and the best methods of applying what was known in regard to their peculiarities. The present indications warrant the statement that in a few years' time the alternate current will be applied to fully as many and as important uses as the continuous current now is. To explain some of the principles of these currents and to describe the mechanism of apparatus to which they have been applied is the object of this work.

CHAPTER I.

ALTERNATE CURRENT DYNAMOS.

Alternating current dynamos depend for their operation upon the same principles of magnetic induction as do continuous current dynamos. Although the form and details of construction are somewhat different in the two machines, the current produced by each is of precisely the same nature and quality, the only marked difference being that in the continuous current machine the electric impulses are collected and transmitted to the circuit always in the same direction, while in the other dynamos the current is sent to the line alternately in opposite directions. This result is brought about in one type of machine by the arrangement of a number of magnets presenting ends of different polarity being placed around the armature, the poles of the magnets being arranged alternately. This method is shown in Fig. 1, where the magnets N, S, are arranged radially in a circle with the armature placed at the center. In the cut only an end view of the magnets and the winding is shown, but the length of the magnets is several times greater, to correspond with the length of the armature as shown in Fig. 2. The magnets, for convenience, are all wound in the same manner, but the exciting current is passed through each alternate magnet in a direction opposite to that in which it passes through the preceding one. This result is easily accomplished by causing the current

to enter the first magnet coil at the outer end of the wire, and as it leaves at the inner end of the coil, it is connected to the inner end of the wire forming the next coil, which will produce poles of opposite name at the ends of the magnets which face the armature. The ends of the wire

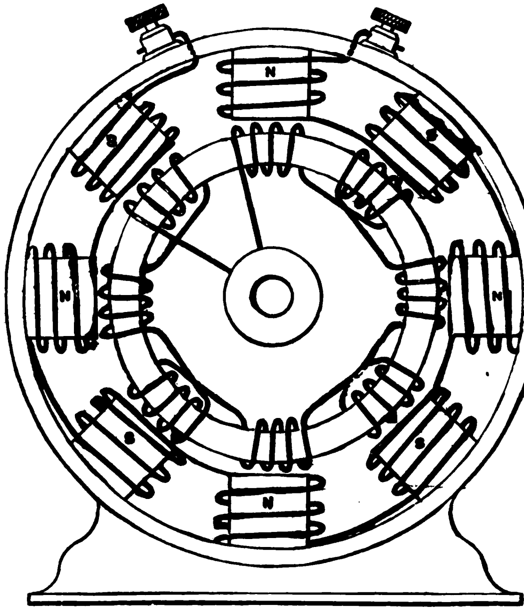


Fig. 1.

forming the magnet or field circuit are generally connected to the terminals of a continuous current generator, generally a small dynamo.

This method of exciting the fields of an alternate current dynamo has been found the most practical, so far, although machines have been made that were self-exciting, but as they require a complication of parts they have not

been used extensively, it being far more practical to employ a separate dynamo for the purpose. The gramme armature, which is a type frequently employed with this form of magnet, is shown in Fig. 2. This armature is almost identically the same as the armature used in continuous current machines, the form and laminations being the same. The winding is also the same, but the manner of connecting the windings of the adjacent sections is quite different.

In the continuous current systems the armature windings are connected in such a manner that the wire may be

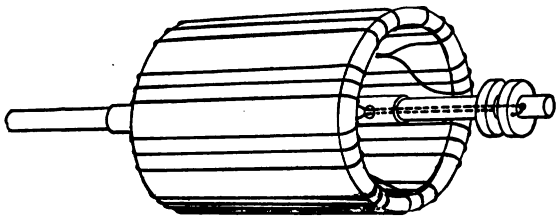


Fig. 2.

said to be one continuous series of turns around the ring with loops brought out at equal intervals and connected to the commutator segments. But when the winding for an alternating current armature is connected up, the outer end of the first coil is left free to form one terminal of the armature circuit, while the other end of the coil is connected to the inner end of the second coil, the outer end of the second coil being connected to the outer end of the third, and so on through all the armature coils; which must be of the same number as there are magnets around the armature. The other terminal of the armature circuit must end the same as the first began, that is, with the outer end free.

These ends are led to two separate insulated collars having a ring of conducting material around their circumference to which the wires are attached. The collector brushes make contact with these rings in the same manner as the brushes on a continuous current machine are brought into contact with the commutator.

The method of connecting the coils of the armature circuit is clearly delineated in the tracing of the circuit on the armature shown in Fig. 1. The reasons for forming the circuit in this manner will be fully understood when it is known that the magnetism from the north pole of a magnet will induce a flow of electricity in a coil of wire in a given direction, while the magnetism of a south pole will induce a flow in an opposite direction, other conditions being the same. As this is the case, it will be apparent from an inspection of Fig. 1, that the flow of current in all the sections of the armature circuit while being in opposite directions in each alternate section, the sum of the electro-motive force produced in all the sections is caused to flow from the same terminal of the armature circuit. When the armature has turned sufficiently to bring a given section under the action of the next magnet pole these conditions are reversed and all the inductions, which are in this case opposite, cause an impulse in the opposite direction. The number of impulses given out during a single revolution of the armature is determined by the number of changes of polarity through which a given section of wire on the armature passes. This will be found to be equal to the number of magnets used. By connecting the armature circuit in this manner a greater electro-motive force is produced than would be the case if the armature sections, containing an equal length of wire, were connected in mul-

tiple—that is, if the connections between each two adjacent sections were brought to the collectors, a loop from the connection between inner ends to one ring and a loop from the connection where the outer ends are together was connected to the other ring. For in the latter case the e. m. f. would only be that due to the e. m. f. generated in a single coil.

In the armatures of dynamos and motors of both continuous and alternating current machinery it is absolutely necessary that the core be thoroughly laminated to prevent heating. Lamination of the armature core is produced by building the core of sheet iron discs (or rings) insulated from each other in some effectual manner, commonly, by placing sheets of thin paper between the pieces of iron. Another method of producing the insulation is by allowing the iron to become thinly coated with rust. Sometimes the iron is painted to produce the same results. Either of these plans work fairly well; but the use of paint is liable to make more or less trouble because it cannot be evenly laid on and for this reason will throw the armature out of balance. The necessity for laminating an armature core becomes apparent from the fact that masses of metal subjected to the influence of rapidly changing intensities of magnetism, have produced within the mass, currents of electricity that expend themselves in heating the metal. These currents may be produced in the wires on the armature if they be very large.

The armatures of some alternate current dynamos do not have any iron in their construction; this is the case in one machine where the armature is stationary, and in another where the armature revolves. In some of the dynamos the armature is stationary while the field

revolves, and in fact the design in alternate current generators admits of fully as many different styles as are employed in continuous current machines. The gramme armature with the style of magnets shown in Fig. 1, is the most common form in use in this country at present, there being several systems using this form of generator, while the details of the machines differ but little. The small continuous current machines used to excite the fields differ more or less in form, but their use and application is the same in each system.

The method of regulation is practically the same in all the systems, and consists in varying the current in the field circuit. This is most frequently accomplished by the use of a rheostat or resistance coils in the exciting circuit. An extra resistance in the main circuit is sometimes used in connection with that in the exciter circuit for the purpose of regulating the current in the mains; but this method must of necessity be wasteful of power. The same result can be attained by varying the current in the exciter circuit.

The leading systems of alternate current distribution in use in this country are the "Slattery," operated by the Ft. Wayne Electric Co., the Thomson-Houston, Westinghouse, Brush, and Freeman. All of these systems, excepting the Brush, use about the same style of generator, consisting of the gramme armature and radial magnets.

The Brush generator has a stationary armature which consists of flat armature coils made of copper ribbon wound on cores of insulating material, and these are supported on a german silver frame, that may be separated at a vertical line through the center, and each half, together with the coils it contains, may be removed from the machine. The terminals of each armature coil are attached to the binding

posts on the frame, while the coils are connected together outside of the armature frame by wires connecting the binding posts. The armature coils are connected together on the same plan as that shown in Fig. 1. The winding of the armature coils shown in a view of one section in Fig. 3, and one-half of the armature containing a similar portion of the coils is shown in Fig. 4, where the plan of connecting the terminals can also be seen. The armature of this machine contains no magnetic material whatever, there being no necessity for any, on account of the armature being so thin that the wires are wholly subject to the inductive influence of the magnets which are arranged on each side of the armature. The thickness of the armature is but 9-16 in., which allows of the magnets on each side being brought quite close together, and as there is no magnetic metal in the armature there is no trouble from the heating effects of eddy currents. The armature frame is also insulated from the frame of the machine.

The magnets of this machine, 24 in number, are attached circumferentially to two discs carried on the same shaft, one-half the number on each disc. The magnets are so arranged that opposite poles face each other on either side of the armature, while adjacent magnets on the same disc are of alternate polarity, and as there is a strong attraction between the two poles all of the lines of force are concentrated so they are cut by the armature wires. By this form of construction the magnets and discs act as a fly-wheel and assist in maintaining a steady motion. To understand just how the flow of current in all the armature wires is in the same direction at any given instant, it is only necessary to infer that the armature coil, when it comes under the influence of an N magnet, has induced

within it a flow of current to the right; while, if under the influence of a S magnet, the flow will be to the left, considering that in each case you are standing at the opposite end of the magnet and facing the armature. Understanding that the direction of flow will be as above stated, it is easily seen that magnets of opposite polarity facing the wire from opposite sides will both combine to induce a flow of current in the wire in the same direction. By applying this idea in an examination of the section of the armature shown in Fig. 3, or the half armature in Fig. 4, an under-

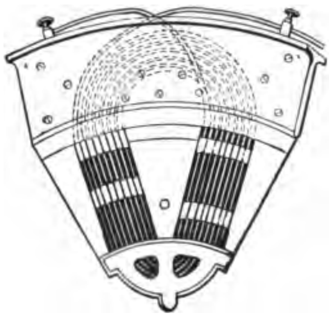


Fig. 3.

standing of this principle of induction may be obtained.

Dynamo electric machines operate wholly on the principles of magnetic and electric or electro-magnetic and magneto-electric induction. The object of these chapters is to show the practical application of the principles, and give as clear an explanation as possible of their operation instead of describing any particular make of machine As the meaning of some of the above terms may not be clearly understood, it may be as well to explain that magnetic induction means induction between two substances sus-

ceptible to the influence of magnetism if one of them be already magnetized, or that magnetism is produced in a

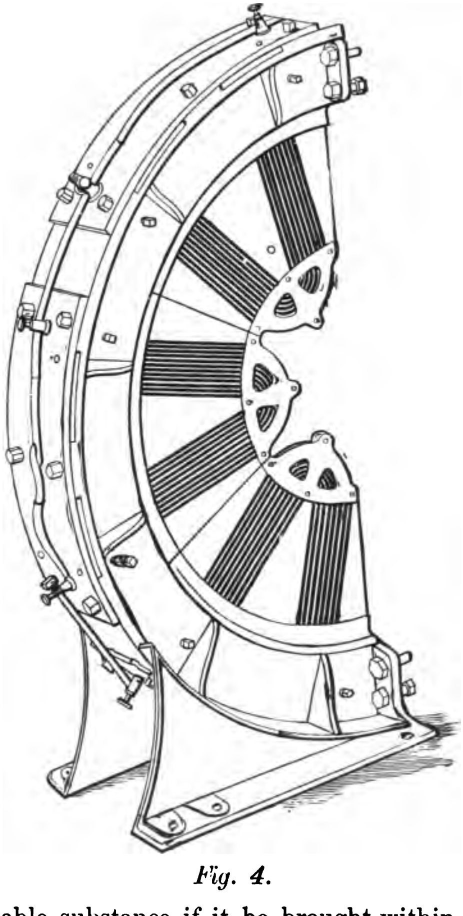


Fig. 4.

magnetizable substance if it be brought within the influence of a substance already magnetized. This principle is applied in dynamos having an armature with an iron core.

Magnetism of opposite polarity is induced in the core where it comes under the influence of the magnet. Electric induction is produced in a wire forming a closed circuit if any change be made in the intensity of a current flowing in a parallel circuit. This latter principle is not utilized by itself to any great extent, as much better results are obtained from the following principles: Electro-magnetic induction may be understood to be the production of magnetism in a magnetizable substance, when it is brought near to a conductor through which a current of electricity is flowing. This principle is applied in all electro-magnets. The magnets of nearly all dynamos are electro-magnets. Magneto-electric induction may be understood as being the principle which causes a flow of current through a closed conductor when near to a magnetic field of varying intensity. This may be explained as taking place when the armature wires are passing through a magnetic field, as is the case in a dynamo when in operation. Take the case of a section of wire on an armature having an iron core, just as the section of wire leaves the field of the magnet. Three separate inductions occur at the same instant, and assist in the production of the current, or rather, the electromotive force; for it is the electro-motive force which produces the flow of current. The armature wire having been near to the pole-piece or end of the magnet, passes from an intense magnetic field to a neutral or intense field of opposite polarity. Passing from an intense to a neutral field gives the condition of a change of magnetic intensity, and when the change is from a field of a given polarity to a field of opposite polarity the change of magnetic intensity is much greater and under these conditions is doubly favorable to the production of e. m. f.

The core of the armature is also magnetized, by induction, and passes through similar changes of polarity at the same instant, and this change of polarity or intensity of magnetism also induces e. m. f. in the conductor on the armature. One or more of the above principles of induction apply in the operation of all electrical machinery.

CHAPTER II.

DYNAMOS (*Continued*).

Another alternating dynamo, the Mordey, having a stationary armature somewhat similar to that shown in Fig. 4, is in extensive use in Europe. The armature differs from the one just described, in having the radial portion of the armature coils parallel with and quite close to the similar portion of the adjacent coils on each side. The pole pieces, which revolve, are a very remarkable feature of the machine as all those on one side of the armature are of the same polarity and all on the opposite side are of opposite polarity. A single coil of wire excites the whole field.

The armature as shown in Fig. 5, consists of a number of coils of copper ribbon wound on a non-conducting core, the different layers or turns of ribbon being insulated from each other. The layers of each coil are fastened together with tape. Each coil is fastened at the outer end between two brackets which are bolted to the frame. The ends of the conductor are brought out through porcelain insulators. The ring which supports the armature coils is made of brass or gun metal and does not come between the poles of the magnets. The core on which the armature coils are wound is of the same thickness as the width of the conductor and when fastened as described, is quite rigid. This ring which supports the armature is in two parts

similar to the one shown in Fig. 4, being divided through a central vertical line. When in position, the two parts are bolted to the bed plate of the machine. With this arrangement, a single coil, if it should become faulty can be

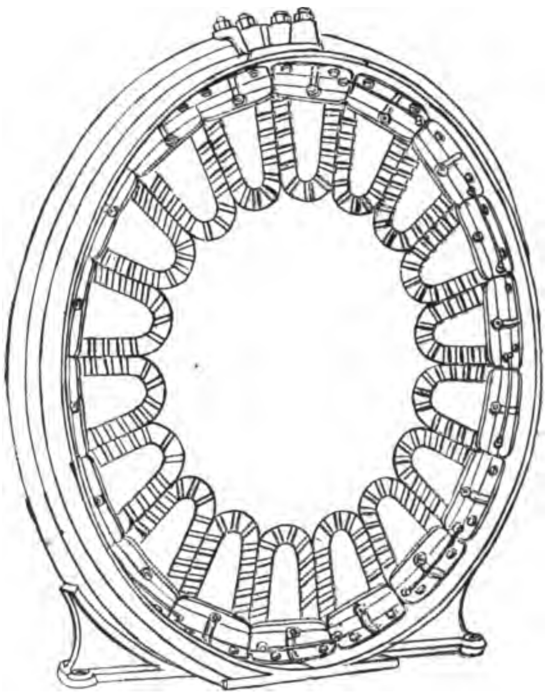


Fig. 5.—Mordey Armature.

easily and quickly removed for repair or be replaced by another. Either half of the armature can be removed without difficulty.

The field magnet of this machine differs from that of all others. It consists of a single electro-magnet the core

of which is a short cylinder of iron fastened to the shaft. The pole-pieces are heavy masses of iron each having nine projections which curve backward and form a magnetic circuit of low resistance, the opposite poles being separated just sufficient to admit the armature without touching, as shown in Fig. 6. The ends of the magnet coil are connected to collector rings on the shaft, as shown in the cut.

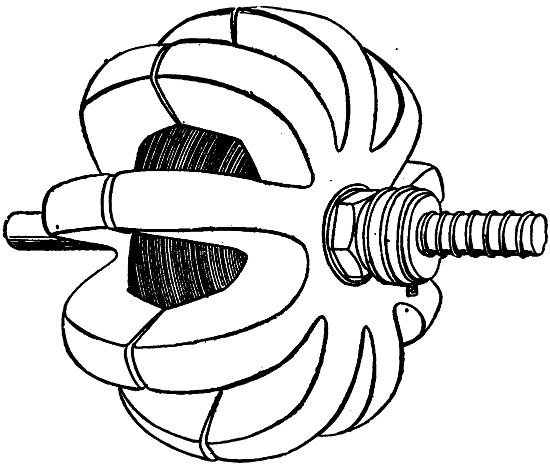


Fig. 6.—Mordey Field Magnets.

The method of joining the armature coils together is similar to that shown on the armature in Fig. 1, or as shown in Fig. 3, the inner ends of two adjacent coils being connected together by short copper rods, on one face of the frame, while the outer ends of two adjacent coils are connected in a similar manner on the other face.

In this machine, although there is but half as many magnets, for the number of armature coils, as in many others, yet the number of alternations of current during

one revolution is the same as in machines having double the number of pole pieces. This may be understood by noting that currents are caused to flow in a coil in one direction by an increase in strength of the magnet and in the opposite direction by a decrease in the strength of the magnet. Both these conditions are present during the time a pole-piece is passing a coil; for as it approaches the coil the strength of magnetism is increasing in density until the pole-piece is exactly opposite the coil, this would create a current in one direction; as the pole-piece leaves the coil the effect is the same as a decrease in the strength of field and produces a current in the opposite direction.

There is one feature about armatures of this kind that may be of convenience at times, and that is the ease with which the machine may be changed from a high potential of, say, 2,000 volts, to one of 1,000 volts giving double the current strength. Various changes in the tension may be made by coupling the armature coils in parallel but the output of the machine, in watts, will remain the same.

Some changes have lately been made in the design of this machine by which it has been given a neater and more symmetrical appearance. The pole-pieces have been connected together from the center to a point much nearer their ends, giving it a smooth outward appearance which has also reduced the amount of surface exposed to the resistance of the air.

The magnet is charged by a current from a small continuous current dynamo.

Another style of thin armature alternating machine is that built by Ferranti. Some of the largest dynamos in existence have this style of armature. Two machines of this type 45 feet in diameter are in operation at the Dept-

ford station, London, England. This armature is shown in Fig. 7; it is composed of a number of flat coils which are made of copper ribbon, each layer being insulated from the others by paper or vulcanite. The shape of the coils is clearly shown in the cut. In some machines they are attached in pairs to a porcelain support which being an

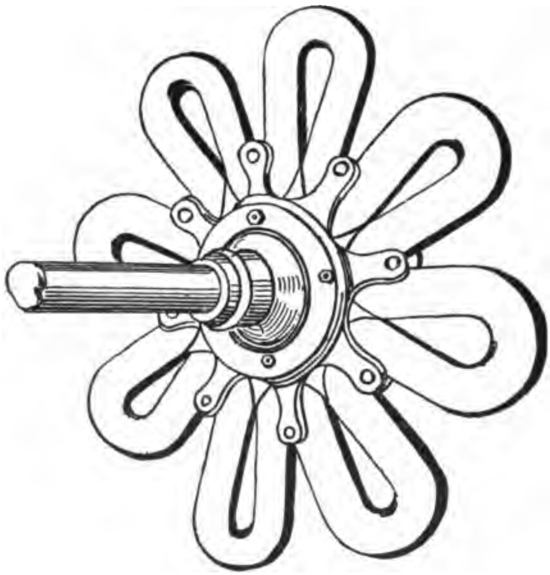


Fig. 7.—Ferranti Armature.

insulator serves the double purpose of holding the coil securely in position as well as insulating it from the core or spider, which has near its edge, recesses into which the lower portion of the support fits. It is secured in this position by sulphur, which is melted and run into the recess around the porcelain and forms an excellent cement for the purpose. In another form of the armature the coils

are held in their places by being bolted to a star-shaped brass spider, which also serves as a terminal for one end of the armature circuit the opposite piece being the terminal for the other end. The collectors or brushes, which in this case are rather heavy hook-shaped castings of brass, make contact with these terminal pieces, which are insulated from but securely fastened to the shaft. The collectors are kept in contact by their weight, as they are hooked on and bear against about one-half of the circumference of that portion of the star-shaped spider fitted to receive them. The armature winding is peculiar, consisting as it does, in the armature illustrated, of four separate copper ribbons connected in parallel. The inner ends being connected to one of the star-shaped pieces and the outer ends to the other one. These strips start in at each alternate section and fold over one another until they all end and are united with the other star-shaped piece carrying, on a portion of its hub, the other collector. There are about 40 layers of this copper ribbon, though the number varies with the size and the e. m. f. of the machine, all well insulated from each other by vulcanized fibre or paper. The thickness of the armature in that portion that goes between the pole-pieces is but little more than ½ inch. This allows the pole-pieces to be brought very close together, producing a powerful field. The armature in one size of machine is but 30 inches in diameter, weighs only 96 pounds and generates current for 1,000 lamps when running at a speed of 1,400 revolutions.

The cores of the magnets are cast solid on each half of the frame of the machine; they are arranged in a circle, projecting inwardly as shown in Fig. 8, where it will be seen that the ends of the cores have a shape similar to that

of the coils. This is necessary, of course, so that the greatest number of lines of force may be brought directly in the path of the coils, as the more concentrated the lines of force and the greater the length of wire that cut them, the greater will be the electro-motive force produced—other things being equal.

The coils of the magnets are insulated copper bars of

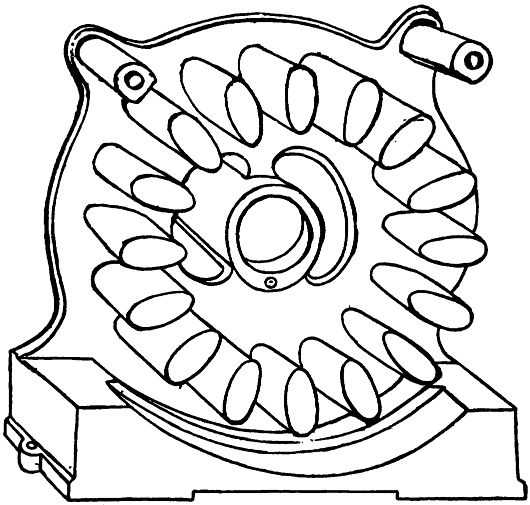


Fig. 8.—Ferranti Field Magnets.

square section and wound in a manner differing from that commonly employed, as a portion of the first magnet is wound in one direction, then the next is partly wound in an opposite direction, and the winding is continued in this manner, alternate magnets being wound in opposite directions until each magnet contains a certain number of turns. The winding is then continued with another bar which forms a given portion of the coil, and this is con-

tinued in the same alternating manner until the opposite end of the series of magnets is reached, when the winding is continued with the third bar. This method is pursued until the winding is complete, when the ends are joined together forming a continuous series of winding. Just what the object is that is sought to be obtained by this complicated method of winding we are a loss to determine, for if the description given, which was found in an English publication, be correct, it seems that nearly the same results might be obtained from the common method of magnet winding, which consists of winding the coils in a lathe, all in the same manner, and then connecting the circuits of each so that the current will flow in an opposite direction through each adjacent coil.

In this machine the collectors are inside of the framework in such position that they cannot be easily got at while the machine is in operation. This is a very good feature and perfectly practicable as there is no occasion whatever for handling the collectors after the machine is started. The collectors of an alternating current dynamo do not require the close attention and perfection of adjustment which is essential to the satisfactory working of the continuous current dynamos with their commutators of numerous segments, requiring the brushes to be adjusted with extreme exactness. With an alternating machine, on the contrary, if the collectors be in contact with any portion of the terminal ring it is all that is necessary, providing they have sufficient surface contact and press hard enough to preserve the conductivity necessary to prevent heating by the passage of the current. But they should not press hard enough to cause heating from friction neither should they be allowed to cut, as they certainly

would if there was undue friction and they became dry. Where the collectors are soft copper and adjusted with judgment, they will run nicely without lubrication of any kind and carry the current without heating or sparking, while hard copper collectors or too much pressure will cause sparking and undue wear of both brushes and commutators.

CHAPTER III.

DYNAMOS (*Concluded*).

Another type of alternate current generator, constructed by Siemens, consists of two sets of stationary field magnets of simple form, each half arranged in a circle on one-half

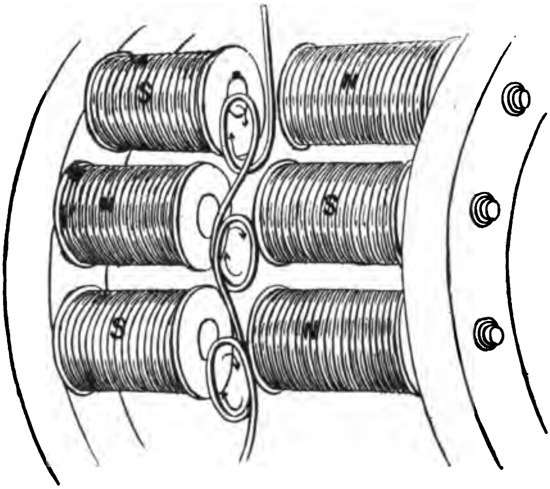


Fig. 9.—Siemens Machine.

of the frame which faces the other part carrying an equal number of magnets. Magnets of opposite polarity are placed alternately around the circle. Each magnet also faces a magnet of opposite polarity. The arrangement is

similar to that represented in several other machines already described, and is applicable to several forms of armature. As shown in Fig. 9, it is plain that any of the radial armatures already mentioned could be used in connection with this style of field, but the armature more particularly adapted to this form of pole-piece is made up of coils somewhat similar to the field magnets, though in some cases the armature coils do not contain any iron, the conductors being wound on wooden cores. The armature coils are attached to the circumference of the disc or wheel which is mounted on the shaft. In some cases the armature coils are quite short and compact, the field magnets being several times as long, but in other cases these proportions are reversed. In some cases the armature coils used with this style of field magnet are somewhat wider at the outside than they are nearer the shaft, as it is thought this shape will cause the conductors to cut a greater number of lines of force and more nearly at a right angle. The field magnet cores extend a few inches from the coil at the back end and are given a slight taper so that a better fit may be obtained where they are attached to the frame. In fitting two or more portions of a magnetic circuit together the best joint that can be made will introduce a certain amount of resistance to the flow of the magnetic lines of force, and the strength of the magnet is reduced in proportion, for it is the number of lines flowing through the magnetic circuit that produces the efficiency of the field.

Perhaps the most perfect magnetic circuit that can be formed when the circuit is composed of two or more pieces is the plan lately adopted by Mr. Foreé Bain, of Chicago, in the construction of his motor-dynamos where the cast iron yokes and pole-pieces are first bored to fit the magnet

cores and are then split and brought into firmer contact by the use of bolts passed through holes in the projecting lugs cast on the pieces for this purpose. In this manner the conductivity of the magnetic circuit is made so nearly perfect that no leakage of the lines of force can be detected at the joints by the most sensitive magnetometer.

The space between opposite pole-pieces, through which the armature coils pass, is a part of the magnetic circuit, and the resistance at this portion is always considerably greater than that of any other portion of the magnetic circuit, and any device that will reduce the resistance at this point will produce a proportionate gain. Several methods are in use for this purpose. By increasing the area of the pole-pieces the greater surface presented to the armature or opposite pole-piece reduces the resistance in proportion to the enlarged surface. Opposite poles facing, exercise an attraction on each other, and the lines of force are drawn directly across. The iron core of armatures forms a conducting path between the poles and assists in reducing the resistance at this point. But in spite of any means so far employed, a portion of the lines of force are lost at this place. The less air space between the pole-pieces and the armature core, the more concentrated the lines of force become; so much so, that when the space is reduced to one-half, it is found that but one-half the length of wire is required on the armature to obtain the same electro-motive force at the terminals. In some of the alternate current machines already described where the magnets which face each other are of opposite polarity and separated but a short distance, the lines of force are quite concentrated so that iron in the armature would not be of much benefit.

The fields of all of the dynamos so far described are excited

by a separate machine and are regulated by varying the strength of the exciting current. This is accomplished by means of a rheostat as previously explained. But a self-regulating constant current machine furnishing alternate currents has been devised and successfully used, keeping the current practically steady under all variations from that of a full load to a short circuit across the binding posts of the machine.

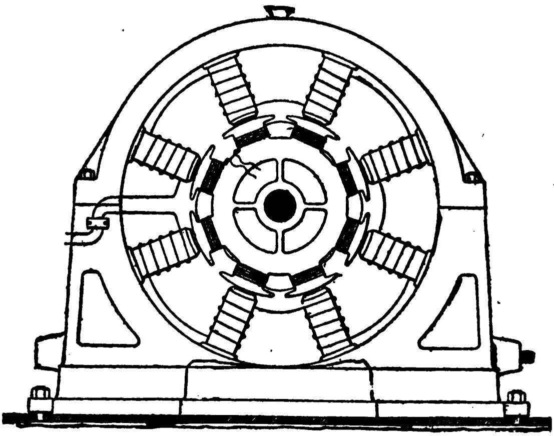


Fig. 10.—Stanley Constant Current Dynamo.

The Stanley dynamo, possessing the characteristics just mentioned was devised for the purpose of operating arc lamps by an alternating current. Arc lamps require a current of constant intensity, whether the current be continuous or alternating. The cut, Fig. 10, gives a front view, in diagram, of the principle features utilized in the construction to cause the current in the armature to operate in conjunction with other features of the machine to maintain a current of unvarying volume on the main circuit. The

armature, shown separate in Fig. 11, is of the polar or radial type, having short cores with extended pole-piece of sufficient width to overlap the edges of two adjacent field magnet cores when in a central position between them. The armature magnets are of considerable length, wound with many turns of wire to produce large self-induction, which is the principle by which the regulation is obtained. The armature core is laminated to the highest practical extent, being formed of thin plates of iron stamped from the sheet. These plates are insulated, one from the other, in a thorough

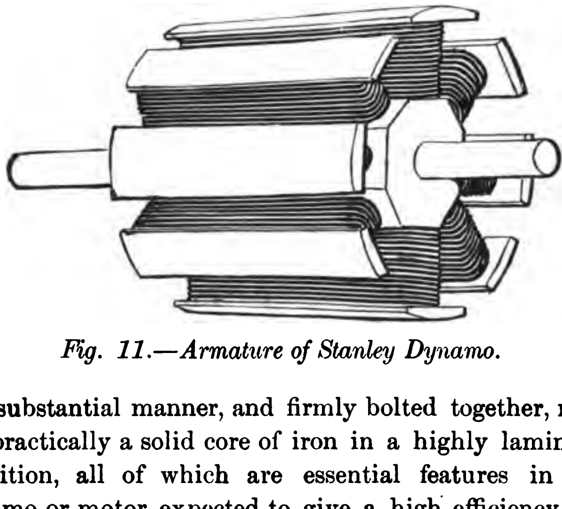


Fig. 11.—Armature of Stanley Dynamo.

and substantial manner, and firmly bolted together, making practically a solid core of iron in a highly laminated condition, all of which are essential features in any dynamo or motor expected to give a high efficiency and work to its full capacity without heating. The cores of the field magnets are solid. The magnets are arranged in a circle about the armature, and radiate toward the shaft. The cores are not provided with polepieces, but on the contrary are somewhat conical. This shape produces a greater concentration of the lines of force near the center of the

pole and assists materially in maintaining the current constant. The winding and connections of the magnets are the same as in most other alternating machines, and the field is excited in the same manner, that is, by a small continuous current dynamo. The regulation of the current is brought about by the self-induction of the current in the heavy coils of wire on the armature.

Self-induction is produced in a coil by the inductive action of the current in one turn of wire of the coil acting on the other turns, when the circuit is made, or when the circuit is broken. When the circuit is made, the resulting self-induction has the effect of diminishing the strength or retarding the flow of the current through the coil, for the flow of the extra current produced is in the opposite direction, and is directly proportional to the resistance of the circuit. Self-induction increases with the number of turns of wire and the amount of iron in the core of the magnet. As the armature of this machine consists of a number of electro-magnets containing a large quantity of iron and great number of turns of wire, the conditions are highly favorable for self-induction, the flow of the current in alternate directions producing an action similar to that of making and breaking the circuit where the current is continuous in one direction.

The action by which the regulation is obtained may be understood from the following explanation. When the armature is in the position relative to the field magnets as shown in Fig. 10, that is, directly opposite, the lines of force from the field magnets are acting with full force, inducing an opposite pole of great strength in the armature polepieces. As long as this continues no current is produced in the armature coils, but if the armature be

revolved, current will be generated in the coils by reason of the reduction in the number of lines of force acting on the pole-piece, and the current produced will be at its greatest tension when the pole-pieces are in about the position shown in Fig. 12; or just as the pole-piece leaves the field magnet. The action of the current in the armature coils excites, in proportion to its strength, magnetism in the pole-pieces, which, acting in opposition to that of the field magnets, reduces the strength of both. This, together with the retarding action caused by the self-

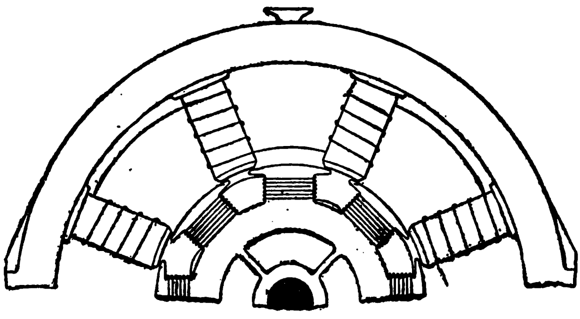


Fig. 12.

induction in the armature coils, opposing the flow of the current produced, maintains the current at a given intensity depending on the amount of iron in the armature poles, the number of turns of wire and the strength of current. It will be seen that if from any cause there should be a momentary increase of current the self-induction would be increased and this would retard the flow, immediately reducing it to the normal amount. If the resistance of the circuit should be increased, by the addition of more lamps for instance, the flow of current would, momentarily, be reduced and, at the same time, the self-induc-

tion would be decreased and immediately the flow of current would increase to the normal amount again.

It will be understood from the above description that the regulation depends almost wholly on the action of self-induction, but it will be understood that it is necessary that the dynamo be run at a given rate of speed to produce the electro-motive force necessary to maintain the standard current through the resistance of the circuit. If the speed should fall below the required rate, of course the regulation could not be so closely maintained; but an increase in the rate of speed would not cause so great a change, because the electro-motive force would be greater than required, but the current in the circuit could not increase because the self-induction would also increase, and its effect would be to reduce the current, so that a practically constant current is maintained under all variations of resistance in the circuit. The foregoing descriptions of alternate current machines embrace the principles upon which the various types of practical alternate current dynamos are built. Other machines, not mentioned, may possess details of more or less importance but the descriptions given will be found to cover all the principal points in the large number of alternate current dynamo generators now in use.

CHAPTER IV.

INDUCTION COILS, CONVERTERS, TRANSFORMERS.

Economy in the distribution of electric energy of any quantity over large areas, or when transmitted to considerable distance, requires that currents of high potential be used. There are several reasons for this: First, that the losses in the conductor are greater in proportion where currents of low tension are used than is the case with high potentials, the loss being inversely proportional to the potential. But the losses may also be represented by the square of the current multiplied by the resistance—C^2R. In practice the resistance of the conductor for low tension currents is low and necessarily so, as an example will show.

An electrical horse-power is represented by 746 watts. To transmit this with a potential of 100 volts through a circuit of no resistance would require an intensity of current of 7.46 amperes, but as a conductor of no resistance is unknown, we will determine the loss in transmitting the same energy through a circuit having a resistance of five ohms. As the loss in watts may be calculated by multiplying the square of the current by the resistance, we have $7.46^2 = 55.65 \times 5 = 278.25$ watts as the amount lost or the power consumed, in overcoming the resistance of the conductor. This amounts to over 37 per cent. or more than 7 per cent. per ohm, and shows the importance of having conductors of low resistance. But suppose the potential

was raised to 1,000 volts and one-horse power to be transmitted. In this case the current, being of a much higher potential, the number of amperes required would be but .74 ampere. Supposing the resistance of the conductor to be the same in this case as in the other, that is five ohms, the loss would now be $.74^2 = .547 \times 5 = 2.73$ watts, which is but .07 per cent. as great as in the former case. As the power developed by a current is reckoned by the number of watts produced, the watts being the product of the electromotive force multiplied by the amperes, it is evident that the amperes may be reduced in the same proportion as the potential is increased, and the same amount of power, in watts, transmitted.

By reducing the amperes, the loss from the resistance of the conductor is reduced, but in a greater ratio. Reducing the amperes one-half will reduce the loss to one-fourth, or in other words, reducing the current reduces the loss directly as the square of the reduction. From this it can be seen that there is greater economy in the use of high tension currents, as far as the resistance of the conductors is concerned. But conductors carrying high tension currents require to be more thoroughly insulated than when the potential is low. For while high tension currents may be more economical they are also more dangerous, and where any portion of the circuit is necessarily exposed that part is a constant menace, liable at any time to cause injury to any one coming in contact with it. This being the case, high tension currents would be impracticable if there was not some way of reducing the pressure at the device in which it is to be used. With continuous currents it has only been possible to do this through the use of storage batteries or accumulators. The alternating current possesses

admirable qualities for this purpose, as through the effects of induction, current can be supplied under reduced pressure at any portion of the circuit. The induction coil with which we are all more or less familiar, is the apparatus through which this effect is secured. An induction coil consists of two separate coils of insulated wire wound on an iron core. The coils must be thoroughly insulated from one another. There are several reasons for this, which will soon be explained. The two coils may be wound one over the other as shown in Fig. 13, and it makes no material difference which is wound on first; or they may be wound side by side as shown in Fig. 14. If the terminals of one of these circuits is connected to a cell of

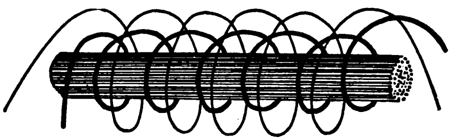


Fig. 13.

battery, including in the circuit a key or other apparatus for making and breaking the circuit, with the apparatus arranged as shown, when the battery circuit is completed by closing the key, a current will be induced in the second coil, if the terminals of the coil are connected to form a closed circuit. The induced current will be of but momentary duration, as it was caused by the change in the intensity of magnetism in the iron core. The softer and purer the iron the quicker it will be magnetized when the current is caused to flow through the coil surrounding it, and the quicker and more completely will the core lose its magnetism when the current is interrupted. It is also found that if the core of an induction coil be made of fine iron wires, in the case of a round core, or of thin iron plates

in the case of a flat or square core, the action is considerably more intense, and the changes occur in less time than is the case when the core is solid. When the flow of current is interrupted there is again a change in the strength of magnetism in the core, and this change also produces a current in the secondary coil. This momentary flow of current in the secondary coil is always in a direction opposite to that of the current producing it. The stopping of the flow of current in the first or primary circuit has the same effect on the flow of current in the secondary as reversing the direction of the current in the primary circuit, that

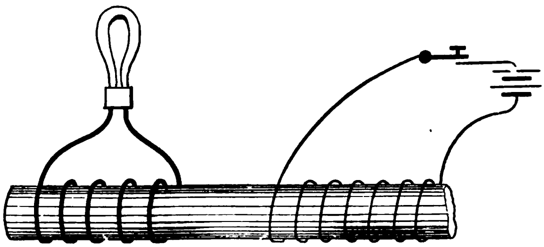


Fig. 14.

is, it produces a momentary current in the secondary coil, flowing in the opposite direction to what it does when the primary circuit is closed.

The effect of induction in coils wound on an iron core is such that the current produced in the secondary coil would be equal to the current producing it, providing the iron core could be constructed so as to interpose no resistance to the flow of the magnetic lines of force, and that the quantity of iron is so great that it will not become saturated with magnetism, and further, the two circuits should be of the same resistance, and contain the same length of wire and the same number of turns.

There is a flow of magnetic lines of force through conductors of magnetism, similar to the flow of electricity through conductors, and different conducting substances offer a different resistance to the flow of the lines of force. A perfect conductor of magnetism, like a perfect conductor of electricity is unknown, all material offering more or less resistance. But in the absence of a perfect conductor the object is to get the resistance as low as possible. In the case of magnetic conductors, the usual practice is to use soft iron of large sectional area and divided or laminated

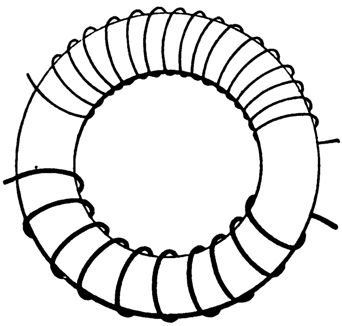


Fig. 15.

in the direction of its length. In cores the cross section of which is round, the iron is usually in the shape of wires, while in flat or square cores it is in thin sheets, and further, it has been found that if each individual wire or sheet is insulated from the others much better results are obtained. Of course there is no insulator of magnetism any more than there is of electricity, and really there is none so good, for there has been no material yet found that will intercept, to any great extent, the magnetic lines of force. But what is meant by insulating the numerous pieces that form the core, is the use of some material that will prevent metallic

contact between the pieces. This is accomplished in various ways. If a coating of rust is allowed to form on the surface of the metal it will answer the required purpose very well. Coating with shellac or rubber has also been found to serve the purpose; also, where sheets of iron are used, paper placed between the sheets serves the purpose and no doubt other means are employed with equally good results. As air offers a much greater resistance than iron to the flow of the lines of magnetic force it is evident that a straight core, or any other form that does not make a complete circuit must interpose an unnecessary resistance. To obviate this, cores forming a complete magnetic circuit have been designed, one form of which is shown in Fig. 15, and others will be shown in figures following.

CHAPTER V.

INDUCTION COILS, CONVERTERS, TRANSFORMERS (*Concluded*).

An induction coil can be operated to transform the energy of the primary current into an alternating current having a greater potential but of less volume than the exciting or primary current or into a current of lower potential and greater volume. This latter effect is what is desired when the current is to be used for the lighting of buildings. By correctly proportioning the winding on the cores any intensity or volume of current may be obtained from the secondary coil, but for obvious reasons the energy obtained from the secondary circuit can never be fully equal to that of the primary current. The high potential of the primary alternating current, which in one system is 2,000 volts, while in another it is 3,000 volts, may be reduced to a 50 or 100 volt current in the secondary by making the number of turns of wire in each circuit of the transformer bear the same ratio as do the potentials in the two circuits. This would be the case if there was no resistance to be overcome, and by considering that one volt per turn in the primary circuit will induce an electro-motive force of one volt per turn in the secondary circuit, the calculation becomes quite simple. Where the reduction is to be made from a 3,000 volt current to one of 100 volts the number of turns of wire in each coil would be in the proportion of 3,000:100 or 30:1, that is there would be thirty times as many turns of wire in the primary coil as in the secondary.

The design of transformers varies considerably, as each designer has his own ideas as to what is the best form, and the relative proportion of iron and copper is calculated so as to combine the greatest efficiency with the lowest cost of manufacture. As the copper wire used is quite expensive, so is the kind of iron required. If too many turns of wire are used for the amount of iron employed the magnetization becomes too great and causes loss, for the resistance of the magnetic circuit increases as the degree of magnetization is increased. If more iron is used a greater length of wire will be required for each turn. This should be kept as small as consistent with the requirements, in order to keep the cost as low as possible. The durability of the transformer must also be considered, and the shape be such that perfect insulation may be had and retained, for the life of the converter depends greatly on the insulation. The rapid alternations of current in the coils and reversals of magnetism in the core produce a static charge in the converter which continually increases in potential until it finds some path of escape. This escape may take place between the two circuits, and should this occur it is liable to produce a leak from the primary to the secondary which would be as much a source of danger as the higher potential of the primary current itself. Several means have been devised to prevent the accumulation of a static charge by allowing it to escape as fast as generated. Probably the first device brought out for this purpose was a sheet of metal introduced between the primary and secondary coils, being of course, thoroughly insulated from the coils. This plate was connected with the ground and as the static electricity which was produced gathered on this plate, a free path of escape was offered through the low resistance of

the ground connection. With this arrangement no charge could accumulate in the converter, for it would pass to ground as fast as formed. Later devices have been brought into use that serve this purpose, and also act as a ground detector. By grounding the center of the secondary circuit the formation of a static charge is prevented; for without the metal shield the charge would form on the secondary circuit, but as there is a ground connection here the charge escapes before it can attain sufficient potential to do any damage. Another plan offered for the same purpose is to connect, in the ground circuit, a burned out incandescent lamp, the broken circuit in the lamp being of sufficient resistance to prevent the escape of the low potential secondary current, but being a sufficient conductor for the escape of the static charged before the potential becomes high enough to cause damage in any way. Still another method for protection is a device consisting of two metal plates separated by a thick piece of insulation. These plates are placed horizontally, and on the lower one is a strip of metal foil. Over the foil the insulation is cut away, leaving a space somewhat larger than the foil. When a static charge has accumulated, under a slight potential, the foil is attracted to the other plate and completes the path for escape. As soon as the charge has escaped the foil drops back to its original position until another charge accumulates sufficient strength to again attract the foil. This device also acts as a ground detector, but its action for this purpose will be explained further on.

The present practice in the manufacture of transformers is to make the cores from thin, soft iron, although in some cases they are made of wire. When thin iron is used

the punched pieces are made of but a few different sizes, for it would be too expensive to make a set of punches for every size of transformer required. The capacity of the transformers is determined, to a great extent, by the size of the punchings. Several of the forms in use are shown in the accompanying cuts, Figs. 16 and 17, where different methods of winding are employed. If the core consisted of a continuous ring it would be necessary to wind the coils by hand, which would be a very slow as well as expensive way. To avoid these difficulties the pieces are designed

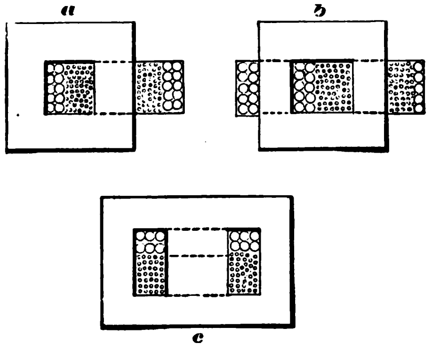


Fig. 16.

so that the coils may be wound separately in a lathe, and the punched pieces then slipped over them or the coils over the pieces. The pieces are then brought together so compactly that the same results are obtained as if they had been previously placed together and the wire wound over them. The way in which allowances are made for this purpose differs more or less in the several kinds, yet they may all be separated into two or three classes. In *a*, Fig. 16, the plates are square, having a square hole punched in the center, a slit being made from one corner of the hole to

the outside, leaving a tongue, over which the coils are slipped. In this case the two coils are superposed ; being wound in the lathe and well insulated from each other they are then slipped over the tongue, additional pieces being added until they fill the coils, which in this form occupy but one side of the core. In *b*, Fig. 16, the sheets are in two pieces, each piece being of a shape similar to that of a try square, the legs being of about equal length, while the primary and secondary coils are wound separate and occupy opposite sides of the core. In putting the core together, each coil is filled with the punchings, after which they are brought together and the ends interlaced, forming a complete magnetic circuit as in the previous case. In the two styles shown, it will be noticed that but one side of the wire is covered with iron, which evidently does not provide for gathering the total number of lines of force which emanate from the wires.

As has been explained before, a conductor carrying a current of electricity is surrounded on all sides by lines of force. These lines produce magnetic action, and will follow magnetic conductors in the same manner as magnetism produced in any other way, but these lines of force will not follow electric conductors, but when they are concentrated by a good conductor of magnetism placed at right angles to the flow of electricity, an electro magnet is produced. As a flow of electricity through a conductor will produce these magnetic lines of force, so a flow of magnetic lines of force through a conductor of magnetism will produce a current of electricity in a conductor surrounding the magnetic circuit at right angles to the direction of flow. But it must be understood that a steady flow of magnetism does not produce this effect, as it is only when the flow

of magnetism varies in strength that the electric current will be produced, and as every increase in the strength of magnetism produces a current in one direction, any decrease in the strength will produce a current in the opposite direction, so it is evident that while a continuous flow of electricity will produce a continuous flow of magnetism, magnetism can only produce an alternating current of electricity.

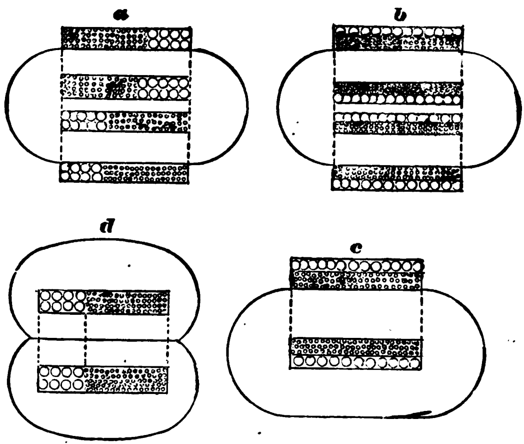


Fig. 17.

That portion of the circuits not enclosed by iron, in the two forms of converters just described, occasions a loss of efficiency which requires that a greater number of turns of wire shall be used than would be required if all the lines of force were utilized. To avoid this loss, or to obtain the same effect from a smaller quantity of wire, the converter shown in *c*, Fig. 16, was designed. In this the sheet has two holes punched out and is slit between them leaving a tongue over which the coils are placed, the two coils being

placed side by side and surrounded by iron on all sides, which insures that a greater number of the lines of force may be utilized. There are other transformers made from sheet iron strips, the forms of which are shown in Fig. 16. In the manufacture of this style of transformer, the coils are wound and insulated in the same manner as those already described. The strips are passed through the coils, the ends bent over and mixed together, making a complete iron circuit. In those shown at *a* and *b* one set of strips may

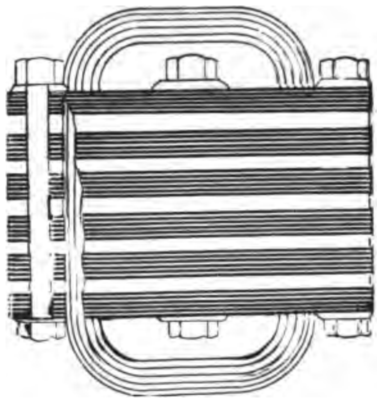


Fig. 17.

be taken and bent into shape, like a hair pin, the coils slipped on and the ends bent over and interlaced, leaving the bulkiest portion of iron at one end. Or two sets of strips bent into the same shape may be used, the ends being lapped and interlaced inside of the coils. The form shown at *c* is built up by taking a set of straight strips, passing the coils over them, bending the ends around and lapping and interlacing at the side, which will make this the bulkiest portion of the core. The form shown at *d* has the iron disposed on both outside and inside of the coils, and is

made by taking a sufficient number of strips to fill the coils, and bending the ends backward over the outsides on both sides of the coils, inclosing them with iron on four sides. It is always an object in the designing of transformers to have both the iron and the copper circuits as short as possible, but the surface must not be so small as to cause overheating, for a sufficient area of iron must be provided so that it will never become saturated with magnetism and a sufficient amount of surface must be had to provide for radiation of the heat generated. As nearly one-half of the space occupied by the coils is taken up by the insulation, it is a delicate matter to get the iron and copper correctly proportioned. It has been found good practice with transformers to use the same method in building up the iron core as is employed by most manufacturers in building up the iron cores of armatures, that is, to introduce, at intervals, a thicker piece of insulation as will be seen in Fig. 17, where the lighter portions in the core represent thicker pieces of insulation. This cut also shows the method of fastening together the sheets forming the core. Several other styles of transformers possessing peculiarities of their own are worth more than a passing glance, and will be illustrated and described in the next chapter.

CHAPTER VI.

TRANSFORMERS (*Concluded*)—FUSES—REGULATION.

Another style of closed circuit transformer built up from iron strips is shown in Fig. 18. In the manufacture of this transformer the coils are wound on a mandrel in a lathe, the opening being afterward filled with the iron strips. After the coils are prepared in this manner, the cores of two coils are placed parallel and connected together by other strips to form a closed magnetic circuit of square form. The strips are interlaced at the corners, making a somewhat greater thickness at this place, but leaving the strips slightly separated, which permits of good ventilation.

The transformer shown in Fig. 19, is of a type quite different from any of those already described. This type is only used for the larger sizes, as small sizes would be difficult as well as expensive to construct. The core is formed of small sized iron wire which is wound on a reel in the form shown. In the winding, after a few layers of wire are laid on, small strips of seasoned wood are laid in at intervals to form spaces for ventilation. The circuits of this transformer are wound on by hand. The spaces for ventilation are not absolutely necessary, as it is quite possible to so proportion the circuits and iron core as to prevent any great amount of heat being generated, but when the construction will allow of being ventilated it is better to introduce it, as the efficiency of the apparatus will be increased by so doing, as well as making a smaller amount of wire

sufficient for the purpose. Ventilation is also provided for in another manner in the winding. Upon the edges of the core along the space to be covered by the coils, strips of insulating material about ⅛″ thick are laid. These strips prevent the insulation of the wire from being cut by the sharp edges of the core and also serve as supports preventing the wire from coming in contact with the iron, leaving considerable space for ventilation.

The winding of the coils on the cores of the transformers shown in Figs. 18 and 19 is built up by first laying on a single layer of the heavy wire that is to form the secondary circuit and over this is wound a layer of the smaller or primary wires. This method of building up the coils is continued until the required amount of wire for both circuits has been laid in place. Ventilating spaces are left between the layers of the coils by the use of insulating strips applied in the same manner as those used on the core. By this means the primary and secondary circuits are so thoroughly insulated and separated, as well as ventilated, that a leak or short circuit between the circuits is practically an impossibility. The ends of the different layers of the circuits may be connected either in series or multiple, a feature which makes a transformer wound in this manner capable of being easily changed to suit different requirements. The secondary coils can be connected so that a 100 volt current or a fifty volt current will be produced. In this manner it may be adapted to lamps of either of the voltages now commonly in use.

Most transformers are connected to the primary circuit in multiple, as the self-regulation is better effected when they are connected in this manner. When transformers are connected to the circuit in series there will be at all

times the same strength of current flowing through the primary circuit of each. This will of course produce a certain electromotive force in the secondaries in accordance with the comparative number of turns in the primaries and secondaries. The strength of current in the secondary will depend largely upon the resistance of the secondary circuit. As the current in the primary is kept constant, when the transformers are connected in series, the e. m. f.

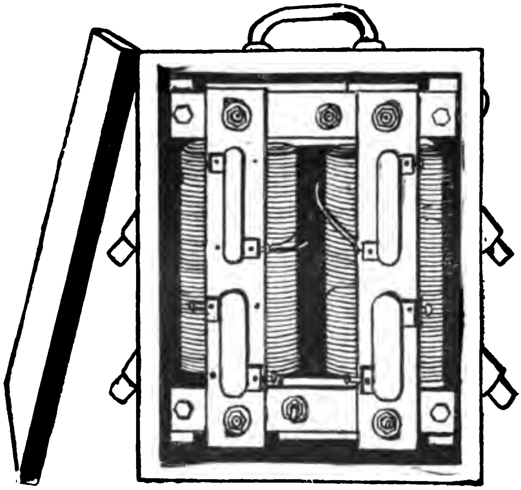


Fig. 18.

in the secondary will also be kept constant. This arrangement would require that the same number of lamps should be kept in action at all times, or if one or more were turned off it would be necessary to supply an equivalent resistance in their place, as the same potential could not be maintained in the circuit unless some method was employed to adjust the magnetism of the cores. Devices for this purpose have been in use but they were unsatisfactory, espe-

cially so when the transformers may be made to automatically regulate in a very satisfactory manner. Another plan for regulating series transformers, was by the use of a choke coil. This is merely a coil of wire having a sufficient amount of self-induction; but this, as well as all other means that have been tried for the purpose, was equally unsatisfactory. The circuits of series transformers are,

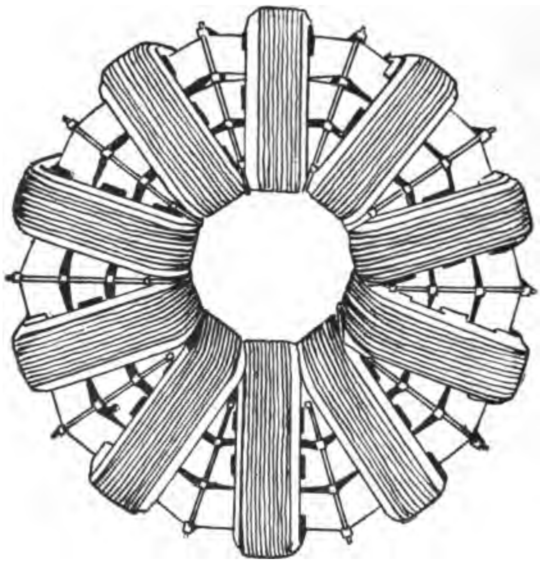


Fig. 19.

as a rule, made to contain an equal number of turns on the basis of a ten-ampere current through the primary.

The transformer shown in Fig. 20, is of the open magnetic circuit type, but it is claimed that it possesses qualities which make it quite efficient in spite of the large air space and consequent resistance between its poles. In this transformer the iron core, composed of wires, is small, so

that there is not much loss in the core, the wires being spread out at each end following the course of the magnetic lines as they bend around to complete the circuit. By this means the loss by induction in the air, is not very great. This form requires a greater exciting current than is required in a closed circuit transformer, but the loss in the primary is much less than the extra loss in the iron when a closed magnetic circuit is employed. The work of the exciting current may be divided into three parts; that portion which is transformed, direct, into the secondary, that spent in magnetising the core and that required in producing the induction in the air. By comparing these with the

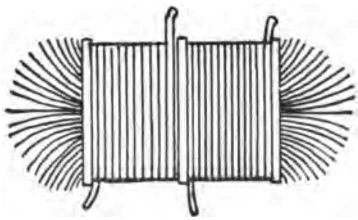


Fig. 20.

losses in a closed-circuit transformer, considering that portion lost in overcoming the resistance of the primary circuit, it is shown there are some points in favor of the "hedge-hog" transformer, as this style is called.

On all transformers connected to the primary circuit in multiple, safety fuses are placed in both sides of each circuit. These fuses are strips or wires of tin or other easily melted metal or alloy, and are placed there as a protection against danger from too great a flow of current, should the wires become crossed or grounded. Should a short circuit occur on the secondary circuit the flow of current would be much greater than the circuits were intended to

carry and the fuses on this circuit would immediately melt and most probably those on the primary would melt also, as the flow of current through the primary circuit of the transformer would also be increased. By the melting of the primary fuses the transformer is completely separated from the main circuit and will remain so, no matter what the cause of the trouble, until repaired.

The automatic regulation of the transformers is easily obtained when they are connected in multiple and a constant potential is maintained on the exciting circuit. When connected up in this manner a nearly constant potential is maintained on the secondary circuit during all changes made in the load, provided the circuit is not overloaded. All work, whether it be lamps, motors or other apparatus operated from the secondary circuit, must be connected in mutiple to assure good regulation. If the transformer is properly designed the current in the secondary circuit will be almost proportional to the number of lamps or other work thrown into circuit, that is, it will be inversely proportional to the resistance of the secondary circuit. The reactions by which this regulation is brought about have been explained in the description of alternating dynamos; how the operation takes place in transformers will also be explained. It depends mostly on self-induction. As the primary coils of the transformers already described consist of many turns of wire and are almost completely surrounded with soft iron, the conditions are favorable to large self-induction. Taking a single coil consisting of a large number of turns of insulated wire wound on an iron core and connected in multiple to a circuit carrying an alternate current, the self-induction will be so great that but a small amount of current can pass through the coil. The num-

ber of turns of wire, the amount of iron in the core, and the intensity of current in the circuit, as well as the number of reversals per second, are all factors that require to be considered in determining the amount of self-induction. A coil of the kind described is called a choke coil and if the core is so arranged that it may be moved inside the coil, it will answer very well as a regulator when the work is connected in series. But such devices are but little used, since the regulation may be automatically obtained.

The reversals of magnetism in iron require an appreciable length of time, which is greater the more nearly it approaches saturation and it must be by means of this and self-induction that the regulation takes place, as the current in the primary circuit of the transformer, which is rapidly alternated, will require time to rise to its full value, being retarded by the opposing action of the self-induced current. The direction in which an induced current flows is always such as to oppose the current inducing it. But supposing the resistance of the secondary circuit is very low, allowing a strong current to flow, the case is somewhat altered. When a current commences to flow in the primary coils, the lines of force set up an opposite current in the secondary. The lines of force due to this secondary current react on the primary current and tend to overcome the self-induction, which allows the primary current to rise more rapidly, thus producing a greater inductive effect in the secondary and causing a greater volume of current to flow. Although the number of turns in the secondary is much less than those in the primary, still the number of amperes is much greater and has a greater inductive effect, which reduces or overcomes the self-induction in the primary. When all the lamps are cut out in the secondary circuit, the resist-

ance is so great that there can be no flow of current in the secondary and the self-induction in the primary becomes so great that practically the current is forced back or prevented from flowing. Should one lamp on the secondary be turned on there would then be a small flow of current in the secondary which would act to slightly reduce the self-induction in the primary. This would allow a small amount of current to flow, and as more lamps are turned on, the resistance of the secondary circuit is reduced and more current flows. As the flow of current in the secondary increases, the self-induction in the primary decreases, and a greater amount of current flows through this circuit. It is easily seen that in this manner a transformer connected in multiple to the primary circuit, becomes self-regulating when the work is connected to the secondary circuit in multiple.

CHAPTER VII.

PARALLEL SYSTEM—SERIES ARC-LAMP SYSTEM.

The usual methods of running circuits for alternating current apparatus is quite simple, although there are systems where special objects are to be attained, such as the use of continuous current apparatus or the charging of storage cells on the same circuit with alternate current apparatus. In such cases more or less complication is inevitable and sometimes a third or extra wire becomes necessary. The diagram of circuits, Fig. 21, shows the usual form where apparatus is to be connected in multiple arc. The primary mains, marked *PM*, are run side by side, as it is necessary that the transformer or other apparatus be connected to both mains. In both branches of the circuit, between the mains and transformer, safety fuses are placed. In practice these fuses are located inside of the iron case that encloses the transformer, an insulated base being provided for that purpose and the connection made in a manner similar to that shown in the transformer, Fig. 18, where it will be noticed also, that provision is made to prevent water from entering the casing; the tubes through which the circuit wires are passed being placed at such an angle as to prevent it. This feature is quite important, as the transformers are usually placed outside the building on account of the possible danger from the high pressure on the primary mains.

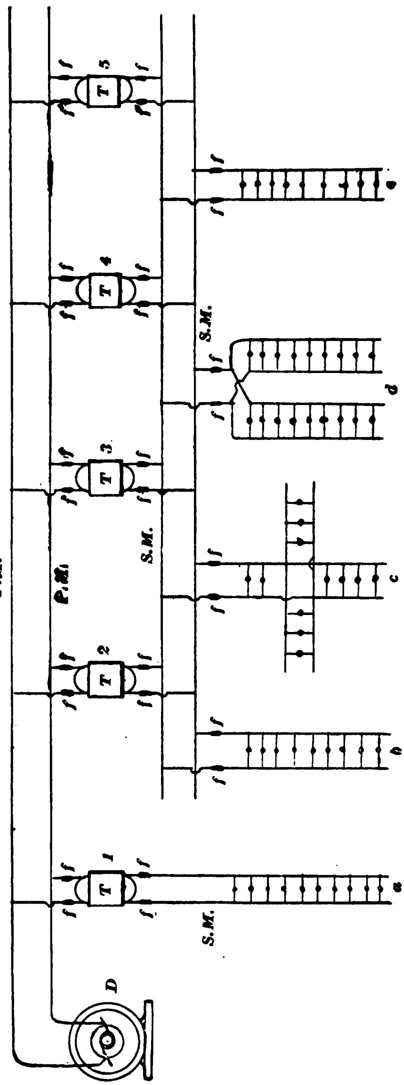


Fig. 21.—Diagram of Parallel or Multiple System.

If the transformers were placed inside the building or within reach of a person standing on the ground, many people through curiosity alone would run serious risks of injury by touching the various parts of the exposed apparatus to see if they would get a "shock." Peculiarities of this kind, in people, as well as some peculiarities of the primary current itself makes it advisable to locate the transformers outside the building. This necessitates enclosing the transformer in a weather-proof casing, and as iron is the most suitable material because it can be readily formed into the required shape, is not easily injured and more particularly, because all the lines of force that would otherwise escape are caught by the iron and by the reaction induce electro-motive force in the circuits, so that there is but slight loss in the transformation of the current. These casings should be as nearly moisture-proof as possible and yet be constructed in such a manner that the interior of the case may be readily examined. This is provided for in most transformers, by the use of a packed joint.

The secondary circuit is provided with safety fuses in a manner similar to that of the primary, the size of the fuses on each circuit being regulated by the amount of current they are intended to carry. As the fuses on each circuit are placed there for safety, they act as a safeguard only when they are made of metal that will fuse or melt by the heat generated by a greater amount of current than they were calculated to carry. The practice that is sometimes indulged in by linemen and station men of putting in a strip of copper instead of the lead or tin strip should be made a criminal offense. Their excuse is that a copper fuse will never "blow." Such excuse shows that they are ignorant of the purpose for which the fuse is intended or are

entirely careless as to the consequences. "Coppering" fuses should never be done even for a short time, or, as is frequently said: "We will copper it so it will run, and fix it all right as soon as we can get a fuse." Such practice usually leaves the fuse coppered until an accident or fire is the result. The fuses are the safety valves and should be kept in good working order at all times, for accidents generally occur when least expected and a coppered fuse may be in place just at the time a fuse that will melt and open the circuit should have been there. Never trust to luck when there is anything more substantial on which dependence may be placed.

Secondary circuits may be led off from the transformer in any desired direction and to comply with any requirements to which the parallel system of wiring is suitable. Several different ways of arranging the circuits are shown in the diagram at *a*, *b*, *c* and *d*, and the diagram also shows how two or more transformers may be connected in multiple to a set of secondary mains from which numerous branches may be taken as circumstances may require. When several transformers are connected in multiple to the secondary mains, in the manner shown, they serve the same purpose as two or more incandescent dynamos connected to the circuit in a similar manner. Transformers are in reality secondary generators and when connected up in this manner the potential on the secondary mains is not increased above what it would be if the mains were fed by a single transformer alone. But when a greater number of lamps are in use than one transformer will supply current for, it is then that the other transformers become necessary and each will, if required, deliver its full capacity of current to the secondary mains.

Transformers, like most other machinery, do not give the greatest efficiency except when working under a given load. The design of most transformers is such that the greatest efficiency is obtained when working at nearly their full capacity. This being the case it will be seen that when several transformers are connected in multiple to the secondary mains their efficiency will be considerably reduced if the number of lamps in use be reduced to less than one-half the full number that all the transformers together are capable of supplying. In such case it would be more economical to cut out one or more of them until those remaining are working at about full load. A single point switch in one of the feeders from each transformer would be sufficient to accomplish this with ease. A close examination of all the features of the inductive system of electrical distribution by the use of parallel circuits will show many points in its favor.

The transformer system of series arc-lighting by the use of alternating currents, consists of a constant (not continuous) current generator of alternating currents, the transformers being arranged in the circuit in series and one or more arc-lamps connected in the secondary circuit of the transformer. When more than one arc-lamp is run from a single transformer the lamps are connected in series as shown in the diagram, Fig. 22, where the dynamo is represented at the left of the diagram, and the transformers at 1, 2, 3, 4 and 5. The numbers on the transformers show their capacity in arc-lamps. The principles of the dynamo and the methods by which the current is maintained at a constant number of amperes are explained in the third chapter of this part of the work. The two circuits composing the transformers are so proportioned,

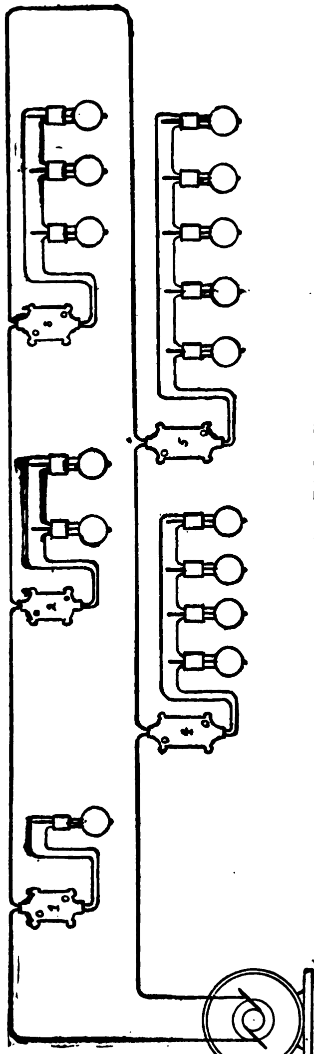


Fig. 22 Series Arc Light System.

as to the size of wire and number of turns in each, that any change in the resistance of the secondary circuit will react, by self-induction, and keep the flow of current constant, in a manner similar to that by which the constancy of the current is maintained by the dynamo. Where two or more arc-lamps are operated from one transformer, any number of the lamps may be switched out without affecting any of the others, even those in the same series.

By this system a number of arc-lamps limited only by the capacity of the machine may be operated from a single dynamo without increasing the potential of the primary circuit to a dangerous extent. The potential and current required by each arc-lamp is 10 amperes and 45 volts and for a small number of arc-lamps the current in the primary circuit would be ten amperes. If the dynamo is required to supply current to so great a number of lamps that the required potential would be dangerously high, the danger would be avoided by keeping the potential of the primary down to a safe limit and increasing the intensity of the primary current to twenty or more amperes. This would give the increased number of watts required which should be transformed into the required potential and current in the secondary. And more than this, two separated circuits, each carrying a constant number of amperes under a varying potential, may be operated from a single dynamo. By such means one dynamo may supply current to as many as 250 arc-lamps, while the potential will not be excessively high at any portion of the circuit.

CHAPTER VIII.

LINES OF FORCE—HYSTERESIS.

In all alternate current apparatus having iron cores that are subject to rapid reversals of magnetism, there is always a certain loss on account of the resistance to change offered by the atoms of iron. The smallest conceivable particle of a substance is called an atom, and with iron it is inferred that each atom may be polarized sc that it will show distinct north and south poles. As any piece of iron consists of an inconceivable number of atoms, each having distinct poles, any magnetizing force which is brought to bear on the iron will cause the atoms to shift their position and set themselves in straight lines parallel with the direction of the lines of the magnetizing force. As these atoms are too small to be distinguished one from the other, it is of course impossible to note the shifting of position that we know must take place, and as the cohesion of the iron is much stronger than the disturbance set up by the magnetizing force no outward change is apparent; but assuming their existence, which has been satisfactorily shown in many ways, and assuming that each atom may be separately polarized, which has been satisfactorily demonstrated, they will then arrange themselves in straight lines, all of the north poles pointing in the same direction. In the mass of the metal, if it is fully magnetized, each north pole will be in contact with the south pole of an adjacent atom. A

nice experiment to determine some of the changes that take place when iron is magnetized, may be made with an electric magnet and iron fillings. If the magnet is connected with a battery of sufficient strength to fully saturate the iron, and having in the circuit a rheostat, and a pole changer that will instantly reverse the current, the apparatus will be found capable of demonstrating many interesting facts in magnetism. By allowing a small amount of current to pass through the magnetizing coil the iron core becomes but slightly magnetic, and it will be found that it has required work to produce this magnetism. If, now, the ends of the electro-magnet be dipped into a mass of iron filings a certain portion of them will cling to the ends of the core and it will be noticed that while the filings are quite thick around the edge, forming a sort of ring, there are but few or none around the central portion of the core. This would seem to indicate that the magnetizing force had acted mostly on the molecules of iron lying at or near the surface of the core. If the current is slightly increased and the magnet again dipped into the iron filings a greater quantity of the filings will be gathered at the ends, and although they still form a ring, the ring is heavier and the unmagnetized circle has become smaller, but, practically, none of the filings cling to the end of the core near the center. The current may be slightly increased at each trial, and it will be found that at each increase the ring of filings becomes heavier and the unmagnetized space at the center is lessened, until, if sufficient current is employed, the whole mass of the iron has become magnetized and the filings cling to all of the exposed surface at the ends. When this result is obtained the magnetism has penetrated to the center of the core;

but its density may be still further increased by an increase of current, and the mass of filings becomes more dense with each increase. As the current through the coil has been increased at each trial it may have been noticed that the mass of filings has assumed a brushy appearance, that is, they have become arranged in lines which appear to be forced apart, and it will be noticed, if the magnetism is sufficiently strong, that these lines will hold their position regardless of the weight of the filings, no matter how much the position of the magnet may be changed. The arrangement of the filings is said to conform to the directions of the lines of force. It is asumed that all force is propagated in lines, and as the lines have no breadth there is no limit to the number that may be concentrated in a given space.

It is the case with the magnetic lines of force, that they have no free ends, but must continue until they have made a complete circuit. If a line of force starts from the N pole of the magnet it must find a S pole somewhere. If the S pole is that of another magnet or an S pole induced in a piece of iron, the conditions will be complied with so far as it may influence the first magnet, but the lines of force will continue on until they have completed the circuit and returned to the first magnet, or been lost in overcoming resistance. As the resistance of the air is much greater than that of iron, the lines of force, no matter how concentrated, are mostly overcome and lost by a short passage through air or other matter offering a high resistance. It is this loss of the lines of magnetic force by their passage through a medium of high resistance that makes it so much of an object to dynamo builders to have the iron core of the armature as close to the pole-pieces of the magnets as

possible, for when the distance between them is increased ever so slightly an increased number of the lines of force, or an increased area over which they may be received, is necessary to obtain the same result.

The concentration of these lines in such a direction that they may be cut at right angles by the wires on the armature is the principal reason for having iron in the armature, as its presence would not be necessary to the efficiency of the machine if the lines of force could be caused to take the desired course without the use of this medium of greater conductivity. In some machines where an N pole faces a S pole and the armature wire revolves between, iron in the armature would do no good, as the two poles carry the lines directly across and the armature wire cuts them at a right angle. But in other machines where the pole-pieces come nearer together at their edges than do their faces across the space filled by the armature, iron is necessary to concentrate and direct the lines of force.

By referring again to the magnet and the iron filings, it will be noticed that the direction of the bunches of filings, or rather the lines they have assumed, tend to curve around toward the opposite pole. This is the result of the effort to complete the magnetic circuit, and is similar to that of a current of electricity which must return to the generator; no matter how many different paths it may be compelled to take or how many times it may have been split up, all must return to the generator.

In experimenting with the magnet and filings, when there is but a small amount of current passing through the coil and the core is but slightly magnetized, holding but a small portion of the filings, it will be noticed that if the direction of the current through the coil be suddenly

reversed by the pole changer, the greater portion of the filings will still cling to the magnet, the reversal of the polarity having occurred so suddenly and with so little resistance that there was but slight loss.

Now if the strength of the magnet be considerably increased, to near the point of saturation and holding as large an amount of the iron filings as possible, then if the polarity be again suddenly changed, it will be found that there is a much greater proportionate loss. The loss will of course be due to several different causes, among which may be mentioned the resistance offered by the iron core to the sudden change of polarity, which is called hysteresis. This may be considered as being the friction between the molecules of iron when suddenly required to change their position, which must occur each time the direction of the current is changed. If the iron is a solid rod the hysteresis will be much greater than it would be if the same amount of iron was in numerous small rods or thin plates. If the iron is somewhat hard, as is generally the case with rolled iron that has not been annealed, the hysteresis is considerably greater than in soft iron. The harder the iron or steel the greater the hysteresis will be, while with tempered steel the loss from this cause will be almost immeasurably great. A little incident occurred in the factory one day that offered a very good illustration of hysteresis. A dynamo had just been set up ready for testing, but would not generate a current, even when current from another dynamo was passed through the field circuit. Everything about the machine appeared to be all right with the exception of the pole-pieces; there was no field. The pole-pieces would not magnetize until they had been hammered with a heavy

hand hammer for several minutes, when it suddenly became strongly magnetized. This was no doubt an aggravated case of hysteresis, and the hammering had produced vibrations in the particles of iron and reduced the hysteresis so that the iron readily yielded to the magnetic stress.

Another way in which hysteresis is manifested to a considerable degree is by the number of reversals per second to which the iron is subjected. With a given quality of iron, the more rapid the reversals, the greater the loss from this cause, so much so in many cases that the heat developed becomes a serious matter. But it is not altogether the increased rapidity of reversals that produces the greatest loss through hysteresis, as tests have been made where a lower rate of alternations or reversals have shown the greater loss from this cause. The rate of reversals vary in the different alternate current machinery from 50 to 150 complete reversals per second, and it has been shown by carefully conducted tests that in some cases the loss by hysteresis was considerably greater at 125 complete reversals than it was at 100, but when the rate was lowered to 75 per second the loss was considerably greater than at either of the higher rates. From this it is evident that the rate alone is not the whole cause of the increased loss It is evident that a particular piece of apparatus may be suited to a given rate of alternations, and, as is the case with most generators of electricity, will give the best results at a given speed or rate of alternation, for in practice with transformers it is noticed that a considerable increase in the development of heat occurs if the rate of alternations becomes considerably increased or reduced. The more strongly the iron is magnetized, that is the greater the number of lines to the square inch there may be, the greater will be the resistance to a change of polarity and the stronger the effect of hysteresis will be indicated.

CHAPTER IX.

ARC LAMPS—IN SERIES.

Arc lamps may be operated on alternate current circuits with the same ease as with continuous currents, and the lamps designed especially for continuous currents will, for a short time, work equally as well on an alternating circuit of the same current strength, but this is not practical, for the cores of the magnets or solenoids would in a very short time become exceedingly hot and interfere with the continuous operation of the lamp. It has been explained how a piece of iron subjected to rapid reversals of magnetic polarity will become heated by the eddy currents set up in the mass of the metal, and when the cores of armatures are of solid iron or even when the iron is not sufficiently laminated, heating occurs to a disagreeable and sometimes to a dangerous extent, and as the temperature of the iron is increased the difficulty also increases. In all kinds of electrical apparatus containing iron cores that is to be used with the alternating current, it is necessary that these cores should be highly laminated, as has been explained in the descriptions of transformers and armatures.

The rate of alternations in most of the systems in use at the present time varies from 50 to 150 complete alternations per second. A complete alternation is understood to mean a complete change from the beginning of a positive impulse when the current rises to the greatest positive potential, then falls again to zero or the neutral condition

and passing below this produces the negative impulse which attains its greatest potential at about as much below the neutral line as the positive impulse had risen above, then with the decrease to zero of the negative impulse, the alternation is complete. This may be compared to the revolution of a wheel, where a given point on the circumference of the wheel makes a circle about the center, returning to the point from which it started. The hysteresis and heating effects may be reduced to very low limits in magnet or solenoid cores by thorough lamination and this is generally attained by making the cores of annealed iron wires. When a core of this kind is used the magnetism will change nearly as fast as the direction of the current in the surrounding coil and this will, of course, produce an attraction between core and coil the same as that which takes place when continuous currents are employed. In the brass spools, on which the coils are wound, the metal is split lengthwise. This is done to prevent heating, for eddy currents are formed in the brass spools as well as in the iron cores. Slitting the spools serve to break up or rather prevent the formation of these currents and the metal remains cool.

Alternating current arc lamps to be operated in series, one of which is shown in the outside view given in Fig. 23, have two coils, one main coil carrying the full current that passes through the lamp and another coil which is in shunt and of high resistance, containing a great length of wire, causes the lamp to feed. These coils and their cores and connections are shown in Fig. 24, where it will be seen that the coarse wire or lifting coil has two separate windings, and the fine wire coil is in shunt around the arc. The cores of the coils being attached to the opposite ends

of the lever L, pull in opposition; but while the arc is of the normal length there is but a small percentage of the current passing through the fine wire coil and consequently the pull is but slight and only serves to balance the extra pull of the coarse wire coil. This coarse wire coil has a double set of windings that may be thrown

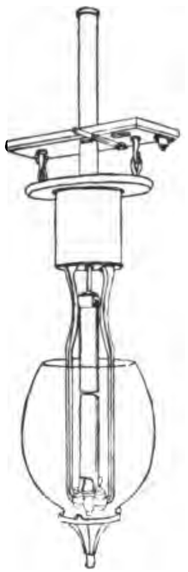


Fig. 23.

together in parallel through the connection at g and the strip h attached to the lever L which is in electrical contact with the frame of the lamp. The action of the lamp may be understood by considering that the current enters at a and passing down to the branch e traverses the lower portion of the coil which is in contact with the frame at c, from here the path of the current is through the carbons

at *d* and out by way of the insulated conductor to the other terminal of the lamp at *b*. When the current is first turned on the lamp, the carbons being together, no current of any consequence will pass through the fine wire coil although it is in shunt around a part of the coarse wire

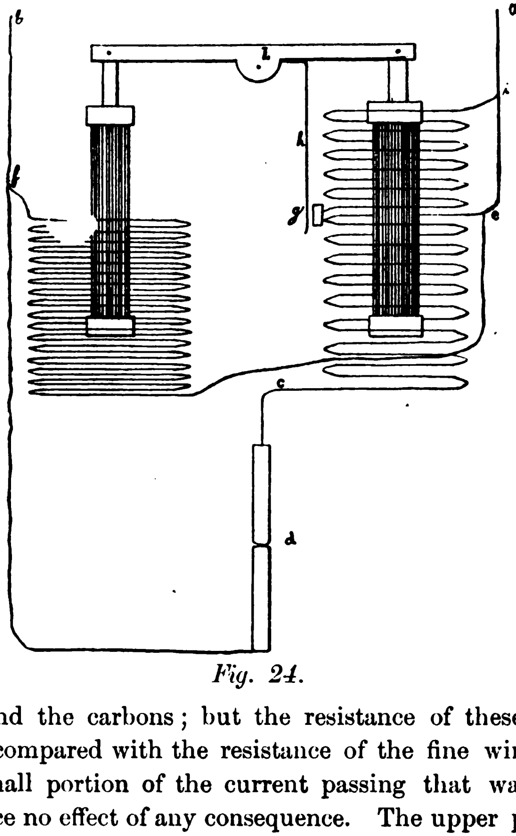


Fig. 24.

coil and the carbons; but the resistance of these is so small compared with the resistance of the fine wire that the small portion of the current passing that way will produce no effect of any consequence. The upper portion of the coarse wire coil will also be in circuit for a moment after the current is turned on or until the core is drawn a

slight distance into the coil. As the upper portion of the coil does not contain nearly so many turns of wire as the lower portion, it alone will not have much effect on the pull exerted by the lower portion, but so soon as the action of the current has drawn the core downward sufficient to break the contact at g, then the full force of the current through the lower portion of the coil will act on the core and draw it downward with sufficient force to cause the mechanism to separate the carbons and form the arc at d in a manner similar to what takes place in an ordinary arc lamp. Flat carbons of considerable width are used in this lamp, the arc traveling back and forth from side to side, but with such rapidity as to give the appearance of an arc the full width of the carbons. As the carbons burn away, both become pointed and the light from the arc is projected upward and downward to the same extent. This is different from the action of the arc produced by a continuous current, for with a continuous current a crater is formed in the upper carbon and the greater portion of the light is projected downward, when the arc has sufficient length to prevent the lower carbon throwing a shadow as is the case with short arcs. In this lamp, as the carbons burn away and the length of arc is increased, a greater amount of current is caused to pass through the fine wire solenoid. This increases its attraction on the core and it pulls against the attraction of the coarse wire coil and shortens the arc, until the decrease of the resistance of the arc allows the attraction of the two solenoids to balance and the carbons are held in this position until they have again burned away sufficiently to again increase the resistance of the arc until the fine wire solenoid draws the end of the lever L down far enough to bring the strip h into

contact with the block g, which shunts a portion of the current through the upper part of the coarse wire coil, and as this is above the center of the core, its action is to assist in drawing the core upward, helping the fine wire coil. This causes the lamp to feed by releasing the clockwork from the brake that held it, and as the carbons approach each other, shortening the arc, the resistance is also lessened and the current passing through the fine wire coil is reduced. This reduces the pull on the lever and its movement breaks the contact at g, allowing the full current to pass through the lower and stronger portion of the coarse wire coil, which then attracts the core and separates the carbons to the distance required to form a full arc of sufficient resistance to shunt enough current through the fine wire solenoid to again balance the attraction of the coarse wire coil. Although there are several changes made in the path of the current, as the machinery is brought into action to feed the carbons downward, and at the same time the length of the arc is shortened and its resistance decreased, yet the changes and movements take place so slowly and to such a slight extent that it is almost impossible to tell just when the lamp feeds, unless looking directly at the clockwork. Even then the movement is so slight, if the works of the lamp are in good condition, being but a single notch on the wheels, that it is hardly perceived. During these changes the intensity of the light remains about the same. An alternate current arc lamp while burning, produces a humming sound, which has been attributed to the rate of alternation of the current and a very plausible theory has been worked out in explanation of the effect. But the explanation may be taken with some allowance, as the same effect has been noticed with continuous current lamps; the humming

sound sometimes rising and falling at each stroke of the engine, causing considerable worriment for fear the engine was not running steadily. The sound was found to be caused by microphonic action, the globe and frame forming a kind of sounding board. When those were damped the sound ceased to be noticed.

CHAPTER X.

ARC LAMPS—IN MULTIPLE.

Another arc lamp designed to work in multiple, with an alternate current, and used with the Slattery induction system, is shown in outline in Fig. 25. The lamp is of the

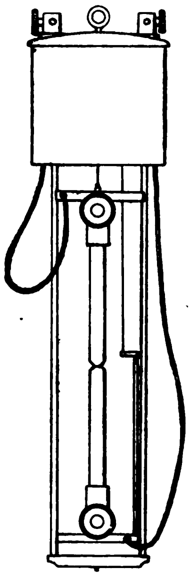


Fig. 25.

focusing type, the lower carbon being fed upward as the upper carbon descends, maintaining the arc in the same position. This dispenses with the carbon rod and leaves no necessity for a chimney, which permits of shortening

the lamp nearly one-half, as well as making it less expensive to construct.

The works of this lamp are exceedingly simple, the main

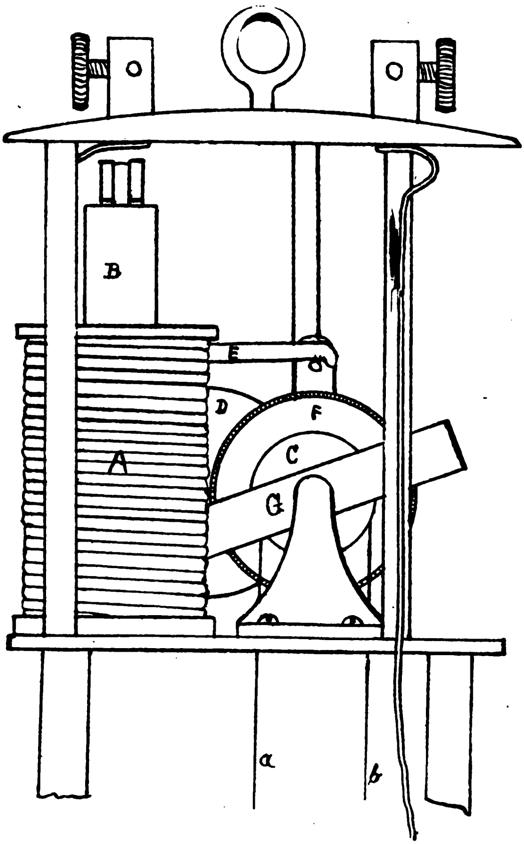


Fig. 26.

portion of them being shown in Fig. 26, where *A* is a simple solenoid having an iron core that is drawn into the coil when the required amount of current, about ten amperes,

is passing. This lamp is designed to work on a 50 volt circuit and consequently requires no shunt coil, as the resistance of the arc regulates the flow of current and the feeding mechanism. By referring to the cut it will be noticed that the feeding mechanism is of the clockwork style, the two carbon holders being suspended from the ends of a flat wire that works on the deeply grooved pully *C*, which is fixed to the same arbor as the toothed wheel *F*, which engages with a pinion on the arbor carrying the wheel *D*, which has a smooth periphery. This wheel serves as a brake wheel and the brake lever *E* engages with the rim of the wheel when the end of the lever *G*, which forms one side of a framework holding the wheels and arbors comprising the clockwork, has been raised a slight distance. The lever connected to the upper end of the core *B* is located at right angles to that portion of the works shown in the view given, and is pivoted to a bracket on top of the solenoid *A*. The other end of the lever connects with a dash pot, to steady the motion, and to the framework *G* by a flexible metal strip which allows the core to be drawn some distance into the coil before the clockwork is caused to act and separate the carbons. The operation of the lamp when put into action would be as follows : Considering the operation as it would take place if a continuous current was used (the only difference being in the action of the current in the solenoid on the core, and the fact that no crater is formed by the arc on either carbon), the current entering the lamp at the binding post is conveyed by a short piece of insulated conductor to the coil *A*, and from there by a flexible conductor to the upper carbon holder as shown in Fig. 25, then through the carbons to the lower holder and from there through a flexible conductor to the opposite

binding post. The action of the current while passing through the solenoid draws the core *B* downward, the opposite end of the lever to which the core is attached rising at the same time. The flexible metal strip which connects the lever with the framework lifts the framework and at the same time the brake wheel *D* is brought against the lever *E*. This prevents the clockwork from revolving and as the framework is lifted still further by the attraction of the solenoid on the core, the partial revolution of the grooved pulley *C*, which must occur from the further lifting of the framework, causes the separation of the carbons by raising the upper carbon holder and at the same time lowering the bottom one. This causes the arc to form and increase in length until the resistance becomes so great that the flow of the current is reduced to an amount only sufficient to maintain the arc at the required length. As the carbons burn away the resistance of the arc increases, which decreases the flow of current through the lamp, and consequently the attractive force of the solenoid is reduced, and as the core gradually rises, the frame and the mechanism are lowered, which allows the carbons to move nearer together. This action is continued by the burning away of the carbons, until the end of the frame has been lowered sufficiently to release the wheel *D* from the brake, which allows the carbons to feed together, on account of the upper carbon holder being the heavier, and as this feeds downward the lower carbon is raised an equal distance. As the arc is shortened, its resistance is reduced and consequently more current flows through the coil and the core is drawn slightly downward sufficient to separate the carbons enough to produce the required resistance and maintain the normal flow of current. All of this occurs without the length of

the arc having been varied more than $\frac{1}{32}''$, and as the usual length of arc is from $\frac{1}{10}''$ to $\frac{1}{8}''$ the change is not sufficient to be noticed providing the works of the lamp move with perfect freedom so that they do not stick. The lamp just described is the embodiment of simplicity, as it contains but a single coil of wire and a small amount of mechanism. The carbons used are round and are cored, that is they contain a core of much softer carbon than that forming the outer part. The cored carbon was designed to prevent the hissing noise frequently heard in lamps, but as hissing results largely from too short an arc, an excuse for the use of cored carbons has never been made clearly apparent.

CHAPTER XI.

MEASURING AND INDICATING APPARATUS.

Instruments to be used with alternating currents must, of necessity, differ in some respects from those employed for continuous currents. The rapid alternation of current does not admit of utilizing the magnetic effect of the current to the same extent or in exactly the same manner as with continuous currents, but when the cores of solenoids are built up of soft iron wires, of small diameter, the change of polarity occurring in the cores with the same rapidity as the alternations of current take place, the resulting attraction between coil and core is similar though not so strong as between a coil carrying constant currents and a solid iron core. This principle is utilized in measuring and indicating apparatus in the same manner as it is employed in the lamps just described, where the solenoids are used to lift the mechanism and separate the carbons. In measuring the strength of an alternate current, several questions arise as to whether the measuring apparatus shows the full strength of the current, or only the average strength. One plan by which instruments were calibrated was to pass a continuous current of known strength through an incandescent lamp and measure its candle-power. Then by the use of an alternating current of sufficient strength to produce the same candle-power, the flow of current was assumed to be of the same strength as that of the continuous current

required to produce the same effects. But, as there are times during each alternation when the current is at a point of no potential, it is evident that this will have a cooling effect on the carbon, and to overcome this, greater current strength will be required. But this is not of so much importance as having some method of comparing the rate of flow or potential in a way that may be made practical for the different purposes to which the current may be applied.

An ammeter of the solenoid type, designed to measure up to about 30 amperes, is shown in Fig. 27, where a short solenoid, composed of a flat copper strip, wound in a spiral form, the layers being insulated by a strip of insulation wound in with the copper, is used. The core of this solenoid is of about 5-16″ diameter, the length being about three times the length of the coil, differing in this respect from the corès used with continuous currents, where they are usually of the same length as the coil, although this is immaterial, for a core of any convenient length can be employed with good results, the greatest effect being exerted, if the core is short, when one end of it is at the center of the coil, the attraction being neutralized when the center of the core is at the center of the coil. In the ammeter shown, the upper end of the core is attached to one end of a plate, the other end of which is a toothed rack, the pitch line being the segment of a circle, and the center being pivoted at some distance from the center of the dial so that the teeth engage with a pinion at the center. The needle or pointer is attached to the arbor that carries the pinion. A counterbalancing weight, by which the instrument is adjusted, is attached to the arbor which carries the plate. A very little movement of the core, in entering the coil, is

sufficient to cause the pointer to move over the whole extent of the scale. By the use of this arrangement the attraction on the core is almost directly proportional to the increase of current, so that the divisions on the scale are

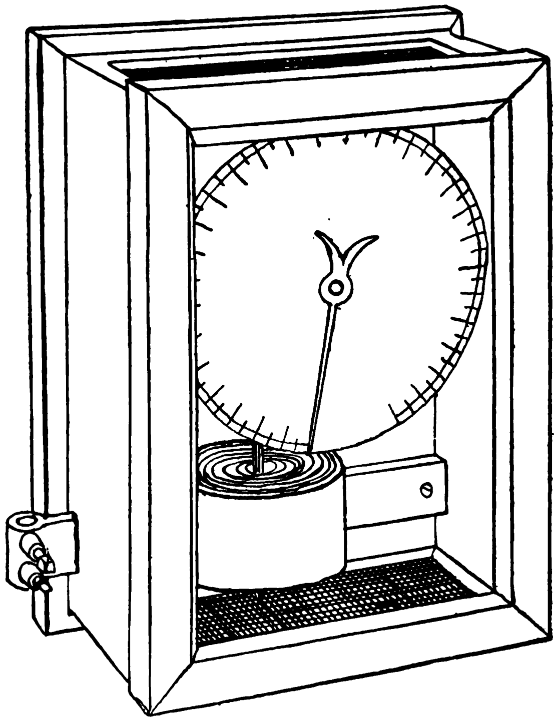


Fig. 27.

equal and have equal values. The slight difference in the attraction exerted on the core is compensated by the counterbalance weight on the lever, which, as it is raised traverses the arc of a circle and requires more force to move it through a given distance when the lever has assumed a

horizontal position than would be required to move it through the same distance while it was more nearly vertical. The toothed rack and pinion, in this instrument, is similar in arrangement and action to that found in some steam guages.

Another ammeter which works on similar principles, but is designed to measure heavier currents, is shown in Fig. 28. The solenoid *S* is quite short and is wound with several small wires, *L L*, grouped together, that when taken together have sufficient carrying capacity to carry, without heating, the full current which the instrument is designed to measure. Another reason for using a number of small wires is that they are more easily wound than a larger one. The core *C* of this instrument is made in the same manner as those used in the other instruments of the same type for measuring alternating currents, which consists of soft iron wires. The lever to which the core, the counterbalancing weight *W* and the pointer *F* are attached is pivoted at *A*. The calibration is effected by means of the weight *W* which is fastened in the required position on the lever by means of lock nuts, shown on the end of the lever. The small projecting arm *T*, which is covered with a piece of soft rubber tubing, is used as a stop to prevent the weight from falling lower than is necessary to bring the pointer to the zero of the scale. Another small arm, covered in the same manner, is placed near by and catches the weight at the side. These arms are adjustable and are necessary to catch the weight as it falls, when the current is cut out of the instrument, for if some means were not provided for this purpose the jeweled bearings, in which the lever is pivoted, would soon be ruined, rendering the instrument anything but reliable. The core is surrounded with hard rubber bands which pre-

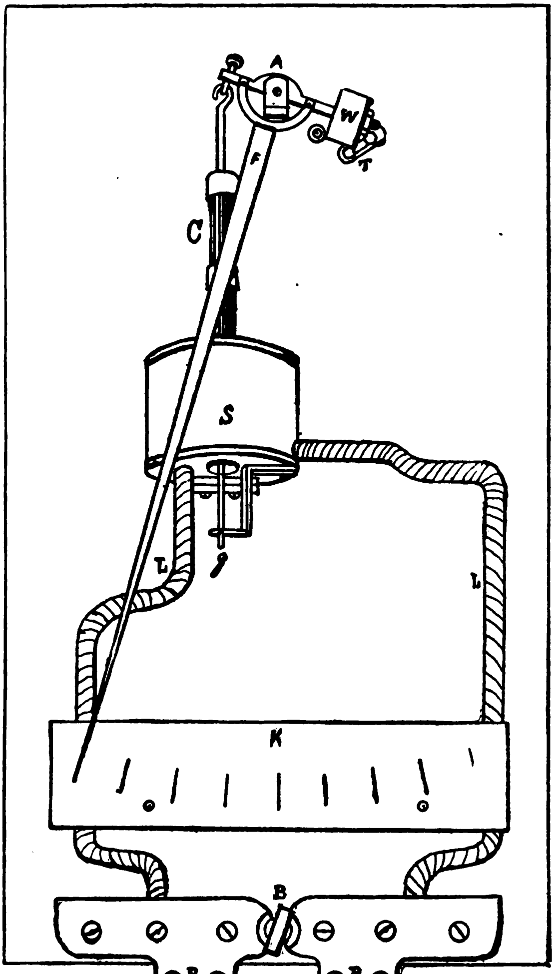


Fig. 28.

vent contact of the iron with the spool on which the wire is wound, as well as serving to hold the core solidly together. The core is also provided, at its lower end, with an extension, *g*, which passes through a bracket and serves as a guide to keep the core in the center of the coil. The scale *K* is divided and numbered according to the number of amperes the instrument is designed to carry. The brass plates to which the wires *L L* are attached serve as binding posts, the lower portion *P P* being drilled to receive the wires, which may be fastened by the set-screws shown. The extension of the plates which approach each other are drilled and the plug *B* is fitted to them. This plug serves to short circuit the instrument when necessary. These instruments are quite simple in construction and sufficiently reliable for ordinary purposes and are easily adjusted, which is an important feature.

A voltmeter of the solenoid type for the measurement of the pressure or potential of alternate currents, and designed to be used as a standard instrument, is shown in Fig. 29, where it will be seen that two coils cf fine wire are used, but only one of them is really a solenoid or has any direct action on the core, whose movement moves the pointer. Another peculiarity of this instrument is that the needle or pointer does not traverse a scale or dial to indicate the difference of potential of the current. The coil or solenoid *S*, in which the core *C* is partly inserted, acts in the same manner as similar parts in other instruments of this type, which have already been described. The core is attached to one end of the cross-arm *D*, while at the other end is a counterbalancing weight *E*, by which adjustments may be made.

The longer fine wire coil *R* is employed as a resistance

only, and is connected in series with the solenoid *S*. The square rod *B*, on which the slide *A* is fitted, is graduated,

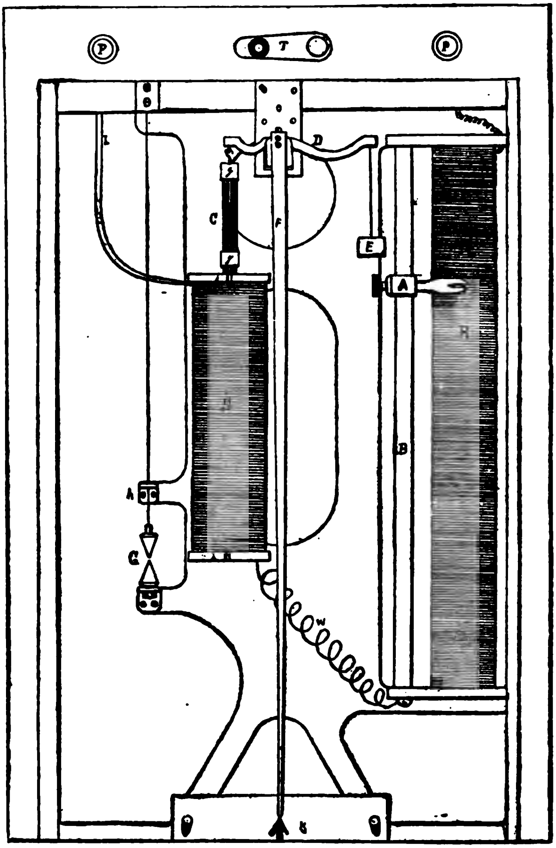


Fig. 29.

the graduations corresponding to the number of volts that will be indicated by the end of the pointer standing over the mark at the bottom of the instrument, when the slide is set

at a given position on the scale, and the shunted current is passed through both of the coils. The number of turns in the amount of current which traverses them, and the size and length of the core, are all to be considered in determining the amount of attraction which is exerted on the core. In order to simplify the construction of the instrument as well as to make it so that it can be used for the measurement of currents of various differences of potential, as well as for the potential of currents of different periods, the resistance coil *R* is introduced to regulate or modify the flow of current. This coil serves virtually as a means of increasing or decreasing the resistance of the solenoid circuit without changing the number of turns of wire of which it is composed. The current entering at the binding post on the right, traverses a number of turns of the wire in coil *R*, then passes to the slide *A*, and through the bar *B*, which forms a part of the circuit, and from there through the fine wire *W* to the solenoid, thence through the wire *L* to the other binding post *P*, which completes the circuit. Where the spring of the slide *A* presses against the coil *R*, the insulation is removed from the wires so that electric contact is made, and the current passing through the coil is shunted by way of the spring.

There is one thing about solenoid instruments, when used with alternate currents, that deserves particular notice; that is the effect produced by self-induction. It has been explained that when the flow of current through a coil of wire commences that a current is produced by the induction of the current in each turn of wire, and that the induced current tends to flow in a direction opposite to the inducing current, thus setting up a resistance or retardation to its flow. Also when the current is interrupted or stopped,

self-induction occurs between the turns of the conductor, but in this case the induced current is in the same direction as the inducing current, which practically, by a combination of the two currents, greatly increase, at this instant, the potential as well as the intensity of the inducing current. Now the frequency with which these changes, the starting and stopping of the flow of current, are made, has considerable effect on the self-induction, and for this reason it is plainly evident that an instrument, designed to work or record at a given number of periods or alternations per second, will not give the same results when used with currents of a different rate or alternation, even when the electro-motive force may be, in reality, the same in both cases. But when a resistance that can be easily varied is introduced into the circuit in a manner similar to that shown in the instrument in Fig. 29, it is clear that the instrument may be calibrated for currents of different periods as well as of different potentials. To make this somewhat clearer it may be well to state that time is required for the magnetic effect to become fully developed or to wholly disappear after the flow of current ceases. This has been so satisfactorily demonstrated that it admits of no question. As the time is so very short it is not noticed in the action of ordinary apparatus when continuous currents are employed, but with alternate currents whose reversals occur many times per second, the iron core does not at any time develop the full number of lines of force due to the number of ampere-turns in the coil and the amount of iron in the core. The slower the reversals, the more time will be allowed for the magnetism to penetrate. The more rapid the alternations the less will be the magnetic effect produced.

A simple and convenient device for leveling the instru-

ment is shown at *G*. This consists of a plumb-bob suspended from the top of the case, and, when the instrument is correctly poised, the point of the weight occupies a position directly over a similar point securely fastened to the frame of the instrument. The necessity for leveling the instrument is apparent from the length of the pointer, and more so on account of the core of the solenoid requiring the utmost freedom of movement within the coil and as the hard rubber bands *j j*, which are necessary to preserve the solidity of the wire core nearly fill the space in the spool, it is necessary that the position be exact, for if the bands should come against the spool, the retardation from the friction produced, slight though it might be, would interfere with the correct indicating of the instrument, for the force of attraction exerted on the core is but slight at best, as the instrument is not designed for the purpose of doing any great amount of work, but merely to afford an indication of the pressure of the current in the circuit. Many times when a circuit has been working badly and the tests made indicated that everything was in good condition, it would eventually be found that the trouble was in some of the more delicate parts of the system where the utmost freedom of movement was required, but was retarded by the slight friction of one piece lying against another, when the design of the instrument intended that the pieces should not come in contact. A similar condition would be produced, in the voltmeter shown in Fig. 29, if, in leveling the instrument, sufficient care was not taken to insure that the core should move inside the spool without touching the sides. It is thought by some persons that the slight friction produced from this cause is not sufficient to interfere with the working, as they say, "the current will

pull that all right," without considering that the force of current in such cases is extremely slight, and that the least friction in the instrument requires a very large proportion of the strength of the current used in the device to overcome it. Remembering these points, it is well to give strict attention in placing such instruments, in order to make sure that no difficulty can arise from the little points, such as those just mentioned. It is the little things that usually produce the most trouble and anoyance, and if the subject is investigated closely, it will be found that it is only through the little things going wrong that the great accidents are possible. It is impossible that too close attention can be given to the small points of a system, for on their condition depends the success of the whole affair.

CHAPTER XII.

HOT WIRE INSTRUMENTS—MEASURING INSTRUMENTS.—*Continued.*

Another class of instruments for the same purpose are those in which the heating effects of the current cause the expansion of a wire which forms a portion of the circuit. These are called "hot wire" instruments. As all substances offer more or less resistance to the passage of the current, work is required to overcome the resistance and this produces heat which causes the wire to expand and increase in length. Several voltmeters have been constructed on this principle, and, by taking the effects produced by a given current as the unit of measurement, it is evident that an instrument constructed on the hot wire principle will be found useful with both continuous and alternating currents.

The Cardew voltmeter is an instrument of this kind, and, as shown in Fig. 30, conveys a good idea of the manner in which the principle is employed. In this view the interior of the instrument is shown as it would appear with the back part of the case and the tube removed. A platinum wire, of sufficient length and small diameter to offer the required resistance, is attached by its ends to the small brass blocks *M* and *N*, which are in electric contact, through the conductors, with the binding posts on the sides of the instruments. The wire is led from the brass

block *N* over a grooved pulley near the bottom of the instrument. There are two of these pulleys on a small

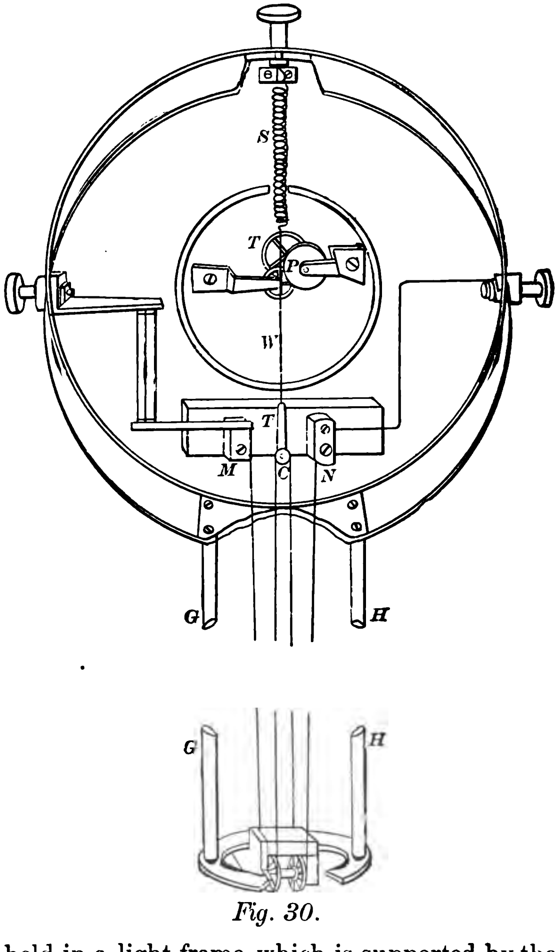


Fig. 30.

shaft held in a light frame, which is supported by the rods *G* and *H*, which at their upper ends are firmly attached

to the case, while at their lower end they are secured to the ring to which the pulleys are attached. From the pulley at the lower end the wire leads up to and over the small pulley at *C* and down again to the other pulley at the bottom, and is then brought upward to the brass block *M*, where it is secured. Between this block and the binding screw a fuse is introduced to protect the wire from the effects of too strong a current, if by chance the instrument should be connected to a circuit of too high a potential. The fuse consists of a short piece of platinum-silver wire which will melt and break the circuit before the current can develop sufficient heat to injure the longer wire. This fuse wire is placed in a slit along one side of a strip of vulcanized fibre, held in position between two flat brass springs, which form a portion of the circuit. A round-headed brass screw is screwed into either end of the strip and the ends of the fuse wire are attached to the screws. When the fuse block is inserted between the springs, the screw heads fit into holes near the ends of the spring, making a good conducting contact and completing the circuit, while the heads of the screws, by fitting into the holes, hold the block securely in place. This is a very convenient arrangement for the purpose, as several such fuse blocks may be kept ready wired so that if a fuse should melt it could be replaced by merely removing the back of the case, removing the fuse block and replacing with another. This can easily be done by simply springing them out of and into place, no tools being required for this purpose.

The central pulley, over which the long wire passes, is attached to a small strip of brass *T*. One end of this brass strip has attached to it a fine wire *W*, which passes around

the pulley P and is attached to the spiral spring S. The tension of this spring can be adjusted by the adjusting screw at the top of the case, the spring serving to keep the wire taut and take up the slack when the wires are lengthened by the expansion due to heat generated by the passage of the current. When connected to points of a circuit having different potentials the current enters at the binding post and passes to the block N, then follows the wire down to the pulley at the lower end of the frame, then up and over the pulley C, thence down around the pulley to the other end of the frame, then up to the block M, and from there through the brass spring, fuse wire and upper spring to the other binding post. The amount of current passing through the instrument will, of course, be quite small, owing to the great resistance of the wire, but slight as the flow of current may be it will sensibly heat the wire and cause it to lengthen. The expansion is so small that it could not be observed with any degree of exactness unless some means were employed to multiply the distance sufficiently to make it plainly visible. This is done by means of the small wheels and pinion in the center of the case. The arbor which carries the pinion carries also at its opposite end a pointer, which is caused to travel round a graduated scale on the face of the instrument. As the expansion of the wire is taken up by the spiral spring S and the wire W, the pulley P, over which the wire passes, is rotated very slightly, but the movement is communicated to and multiplied in the toothed wheel T, from which the movement is transferred to and again multiplied in the pinion, and the amount of this movement is shown on the scale on the face of the instrument.

All of the shafts and arbors of this instrument work in jeweled bearings, which reduces the friction to so small an amount that it does not appreciably affect the truth of the record given. The temperature of the atmosphere does not affect the working, as all parts of the instrument are affected alike, and the adjusting screw provides a means for instantly adjusting the pointer to the zero of the scale. The wire *W* is small and where it passes over the pulley *P* some special means are required to keep it from slipping. This is accomplished by making a flat space on the face of the pulley and inserting two screws at this place. The wire is laid alongside of these screws so as to give it an offset that will prevent its slipping. This has been found to be the only reliable method of attaining this result, on account of the wire being so delicate that sufficient preasure of a screw head to hold it securely would cut the wire. These instruments, when about three feet long, are capable of accurately measuring potentials up to 225 volts, and are very reliable, as there is no magnetic material about them, consequently they are not subject to the earth's magnetism or that of dynamos or masses of metal near which it may be necessary to use them. All instruments using the magnetic properties of the current are more or less affected by the magnetism in surrounding objects, so much so that when delicate measurements are to made with them, this outside magnetic influence must be measured and allowed for.

A volt meter, for the measurement of low differences of potential or electro-motive forces, such as that of primary and secondary cells, has been constructed on the hot wire principle, in a simple and ingenious manner. The instrument consists of two springs, to which the conducting wires

are attached in the manner shown in Fig. 31, where *a a* are the springs and *b b* are the conducting wires. The short wires, *c c*, are electrically connected to the wires *b b*, and also to the needle *g*, which is the pointer that indicates the difference of potential on the scale *S*. The spiral springs, *d d*, serve to hold the needle in position and cause it to move over the scale when the expansion of the wires

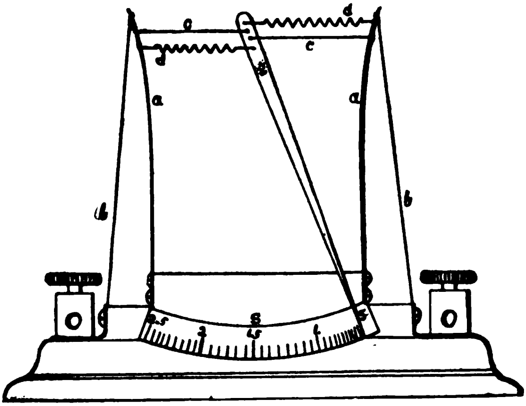


Fig. 31.

b b, which is very slight, allow the flat springs to approach each other. The expansion of the wires, slight as it is, is found to be sufficient to allow a slight movement of the springs, which movements, transmitted to the needle through the short wires *c c*, and an equal amount of movement being taken up by the helical springs *d d*, so multiplies the movement at the end of the pointer that the change due to the potential can easily be read off by the scale.

CHAPTER XIII.

VOLTMETERS.

The instrument shown in Fig. 32, depends for its action on the attraction existing between a conductor, through which alternate currents are passing, and a piece of soft iron in its vicinity. This principle may be applied to the measurement of current strength as an ammeter or to the measurement of the pressure or potential, as a volt meter, the use to which it is applied depending on the winding. In either case the principle and the action is the same, and the attraction between the conductor and the iron piece depends on the number of amperes on the one side, and the mass of iron on the other. In this instrument the wire conductor is wound on ring-shaped reels or spools, which may be of wood or metal; if of metal the reel or spool must be slit to prevent heating from the currents set up in the metal, and the iron is a thin broad strip bent into such a shape as will enclose the coil on three sides. This is attached to an arm on a small arbor which is placed eccentrically in the coil, so that at that portion of the coil nearest to the arbor the iron piece will just pass the reel without touching when the arbor is revolved. The action will be the same whether the iron pieces are arranged to work on the outside or on the inside of the coil. To balance the instrument, as well as to increase its attractive power, two rings of wire and two iron pieces, are employed in each instrument. The arrangement and

location of the coils are shown in the ground plan in Fig. 33, as well as in the front view in Fig. 32. The arbor, with the sleeve *S* and the projecting arms, carrying the iron pieces *C C* arranged on opposite sides of the arbor and at some distance from one another, are shown in Fig. 34 in two different ways in which they may be arranged. As the arbor is placed eccentrically in the rings *A*, *A*, Fig. 32, the rings are set eccentrically to one another, which, in

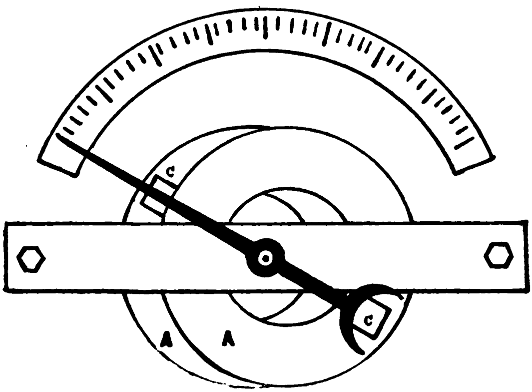


Fig. 32.

a manner, places them opposite, so that the attraction between each ring and the corresponding iron piece is in opposite directions on either side of the arbor, which tends to balance the instrument, as the attraction is upward and outward in the rings in one case while it is downward and outward in the other where the iron pieces act on the inside of the rings. But if these pieces are arranged to work on the outside portion of the rings the action will tend to draw them toward the shaft. But with either arrangement the record is made in the same manner; that is, by causing a pointer attached to the shaft to move over a

graduated scale on which the graduation represent a given number of the units in which the measurement is to be made. The arbor of these instruments is supported

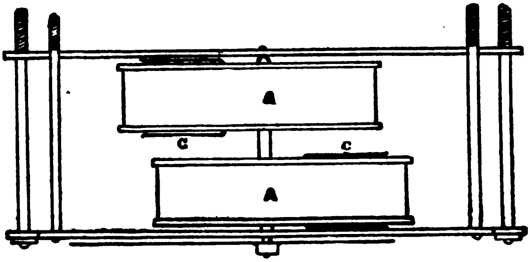


Fig. 33.

at either end by brass strips, which form a portion of the frame work, supporting the various parts. The cause of the attraction between the current in the conductor forming the rings and the iron pieces *C C* is the induction from

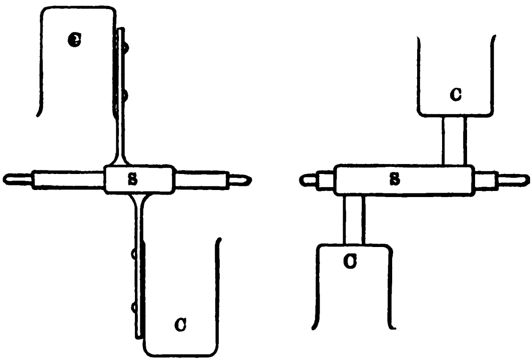


Fig. 34.

the current in the conductor setting up currents in the iron and the action and reaction between the inducing and induced currents, which do not occur simultaneously, but the induced current following the inducing current a

portion of a period behind, so that the resulting action between the two currents is an attractive one. The iron pieces which might ordinarily be called the armature of the instrument, being placed so that when not acted on by the current they are at an angle of 90 to 120 degrees from that part of the ring that stands nearest the arbor. When the current is passing and the attraction occurs, the effect on the armature is to draw it toward that portion of the ring which approaches most closely to the arbor, and consequently it traverses the arc of a circle and at the same time approaches more closely to the ring, on account of the arbor being set eccentrically, the force of the attraction being constantly increased, by the armature and the coil coming nearer together and making the distance less through which the attraction is required to act.

CHAPTER XIV.

SPRING METERS.

A class of measuring instruments, that are very accurate and quite interesting, from the fact that they are constructed on a very simple principle, and one which had not previously been utilized to any great extent, was introduced some time ago by Messrs. Ayerton and Perry. The first of these instruments, designed for the measurement of continuous currents, consisted of a spring made of flat material and wound or twisted into a permanent shape, similar to that of a curled shaving, as shown in Fig. 35.

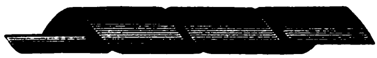


Fig. 35.

With a spring of this kind, any force brought to bear on it, which tends to extend or compress it, will also produce a rotary motion at the ends. A spring of this kind is capable of being made the means of obtaining very delicate measurements of forces of any kind where it is advisable that there should not be a very considerable amount of yielding, as in most weighing machines, for this apparatus really weighs the current. For example, in the case of a spring balance, when it is used as a weighing or testing machine, and acting directly, if the specimen should break or give way, the recoil of the spring is

likely to cause it to get out of order. But in the case of a spring of the kind shown, considerable strain can be withstood without changing the length to such an extent that a sudden recoil would be liable to cause any injury or change the permanent set. Another principle which is used in connection with this style of spring to adapt it to the measurements of electric currents, is the action of the current in a solenoid, on the core. In the case of solid or laminated cores, the action has been explained in the description of several of the instruments utilizing this principle. But the action on a very thin, soft iron tube is somewhat different. In the case of a solid or laminated core of soft iron, placed in a magnetic field which is not uniform, as in the case of a solenoid where the intensity of the field increases from the ends to the center, it will be attracted from the comparatively weak portion at the end, into the strongest part of the field at the center. In this case the core is a temporary magnet, whose strength varies with the strength of the field, but not to the same extent; for while the core is but slightly magnetized, it is capable of more easily absorbing the lines of force than when it becomes more nearly saturated. It is for this reason that the readings will not be proportional to the current strength unless some means are employed to keep the strength of this temporary magnet constant. As a piece of very thin, soft iron tubing becomes saturated in a weak field, it will be acted on proportionately to the increase of current strength, above what is required to saturate it, so that when used, as the core of a solenoid, the force with which it is sucked into the coil, will depend simply, for all fields above that required to saturate, upon the strength of the field, and will be proportional thereto as well as pro-

portional to the strength of current producing the field of the solenoid. To utilize this for measuring the strength of a current, by measuring the pull on such a thin iron core or tube, the tube and spring described are connected together by placing the spring inside the tube and attaching the inner end of the spring solidly to a small brass cap on the end of the tube. The spring must be somewhat smaller in diameter than the interior of the tube to allow the tube to freely rotate around it, and the tube and spring must be kept parallel. The free end of the spring extends some little distance beyond the end of the tube, which should be very nearly the length of the solenoid.

These principles are combined in the instrument in the manner shown in Fig. 36, where the end of the spring is attached to a knob let through a hole in the heavy glass top, which serves to protect the interior of the instrument from the entrance of dust and moisture, as well as forming a transparent support for the end of the spring. At the upper end of the tube, which hangs free, except its being connected to the spring at its lower end, is attached a pointer to traverse the scale. The lower end of the tube, which does not extend to the bottom of the solenoid, is provided with a slender pin which serves as a guide to keep the tube in the center of the helix or coil. If the tube extends to the bottom of the helix the action of the field would have no effect to draw the tube, for the position it would then be in would be such that the attractive force of the N and S ends of the helix would be equalized on the core, and no pull would be exerted ; but when the core lacks about $\frac{1}{8}$ its length of being wholly within the helix, and a similar portion is outside, then the pull on the spring is sufficient to cause the iron tube and the

needle attached to make very nearly a complete revolution around the center. This will be produced by an extension of the spring, so slight as to move the pointer but a trifle nearer the graduated scale of the instrument. If the lower end of the iron tube entered no more than to three-

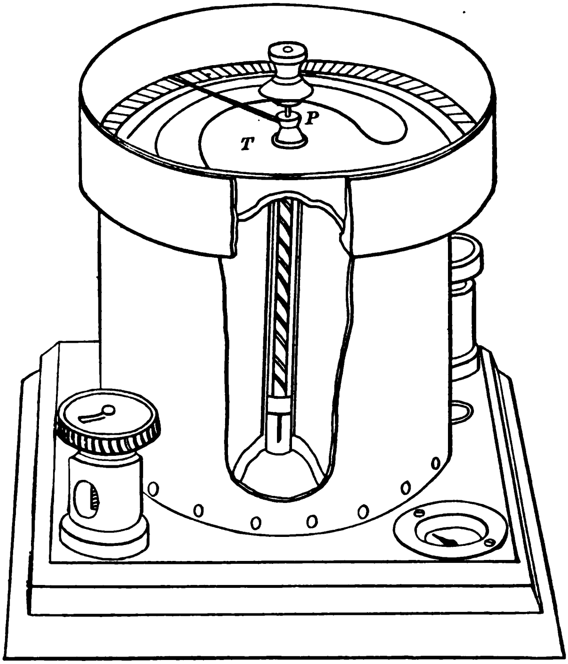


Fig. 36.

fourths the depth of the coil, the pull would be somewhat greater than would be the case if it entered more or less than this, so that the exact calibration of the instrument is a very easy matter if the parts are proportioned approximately correct. The extension of the spring, which

passes through the knob at the top, and serves as a support, by being threaded and fastened by locknuts, provides a means of adjusting the core at any depth required, so that the pull on the tube and the strength of the spring may be correctly proportioned, and indicate according to the divisions on the scale.

When looking at a scale over which a pointer is moved, such as in the instrument shown, or the face of a clock or watch, the apparent position of the pointer, when looked at from an angle, does not coincide with the real position, and where accurate readings are required, it becomes necessary to occupy a position which will bring the eyes directly in front of the scale. To overcome this difficulty and make the reading from an angle correct, a mirror is arranged under the needle, in which it is reflected in its correct position over the scale. The small compass inserted in the base of the instrument, serves to show the direction of the current through the coil, the marked point of the needle pointing toward the binding post at which the current enters. In practice it makes no difference at which binding post the current enters, as the action is the same. But there is a chance for error in the change of magnetism in the iron; but as the iron in this case is very soft and thin, it retains but a trace of magnetism, which a small current will reverse, the error is inappreciable, as the first portion of the scale is not calibrated, for the movement of the needle before the core becomes saturated is not proportioned to the strength of the current. This instrument, although suited by its present construction to the measurement of continuous currents only, could be adapted to alternate currents by some slight changes in the details, which would not modify the gen-

eral principles utilized in its construction. The principle of the spring used in this instrument has led to the development of the twisted strip voltmeter for continuous and alternating currents, which will be found described and illustrated in the next chapter.

CHAPTER XV.

TWISTED STRIP INSTRUMENTS.

Another instrument possessing features of interest and accuracy by which a large range of measurement is obtained, consists principally of a twisted strip. This strip was devised by Messrs. Ayerton and Perry, and is preferred by them to the spring which they have used in a number of measuring instruments made by them. The accompanying cut, Fig 37, will illustrate what is meant by a twisted strip, although but a portion of the strip is shown. The strip used in the instruments have a double twist,

Fig. 37.

that is, the twist at opposite ends, is in opposite directions. Perhaps a better idea of its form may be had by considering, that a narrow strip of thin metal is secured at its ends and the middle grasped by a pair of pliers and held while the handle of the pliers is passed several times around the strip until a permanent twist is given to it. When in this condition, the strip will be acted on by any change of temperature, no matter how slight, to which it may be subjected. If all parts of the strip were free to move, excessive changes of temperature would cause it to twist and untwist to an extent that would be easily noticed. If a pointer be attached to the center of the strip, and its

ends are secured to a bracket having a different co-efficient of expansion from that of the strip, it would serve the purpose of a thermometer, so sensible would it be to changes of temperature. The same strip might also be used as a weighing instrument or for measuring tensile strains. By attaching one of its ends to a support, and suspending the mass to be weighed from the free end, the movement of the pointer, as the strain would partially untwist the strip, would indicate on a dial the weight of

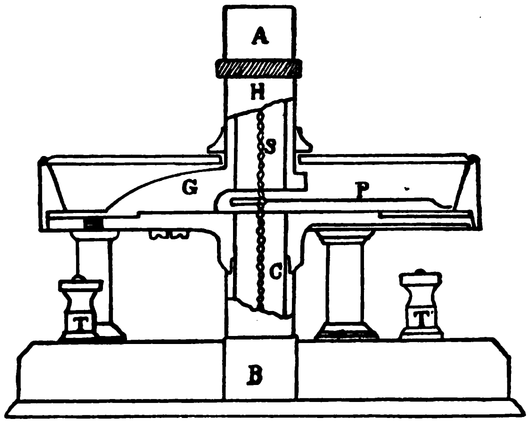


Fig. 38.

the mass. Various useful applications of the principle may be made, and the readings will be accurate and proportional to the distances moved through by the pointer. In Fig. 38 is shown the arrangement by which this principle is utilized for the measurement of electric currents.

In this instrument, a metal bracket *G*, which is supported on the base of the instrument, supports the ends of a tube which is separated at the middle to allow sufficient freedom for the needle *P* to move over the graduated por-

tion of the dial, which forms nearly a complete circle. The twisted strip S is attached by its upper end to the cap A, where it is also electrically connected. The lower end of the strip is mechanically held by the lower cap B, but is not in electric contact with it. The bracket also carries the circular portion containing the graduated dial of the instrument. The lower part of the tube from the point C is of iron, while the upper part is of brass. This arrangement is for the purpose of making the expansion of the tube correspond with that of the spring when both parts are at the same temperature. This does away with the necessity for adjusting the instrument each time it is used. For, if the expansion and contraction of the tube was different from that of the spring, the instrument would require adjusting to the temperature of the room in which it was used, but as the co-efficient of expansion is about the same in both the tube and strip, but little adjustment is ever required. But, to provide for adjustment when necessary, the top cap A is so constructed, that by turning the milled ring below the cap, more or less tension can be given to the spring, which provides an easy method of zero adjustment. It is the heating effect of the current expanding the strip that is made use of to determine the measurement. As the full current passes through the strip and heats it, the increase of temperature causes the strip to untwist, and as each of the ends are prevented from turning, the right and left hand twists cause the middle portion to untwist and carry the pointer around the scale. It is plain to be seen that, as it is the heating effect of the current which produces the action, that either continuous or alternating currents may be measured by this means and the number

of amperes readily determined, for as the full current passes through the strip and sensibly heats it, it is the difference of temperature between the strip and the bracket that causes the movement of the pointer.

When the instrument is arranged for the measurement of potentials, it becomes necessary to make use of a very delicate strip of considerable length, formed from a substance of high electrical resistance. Instruments of this

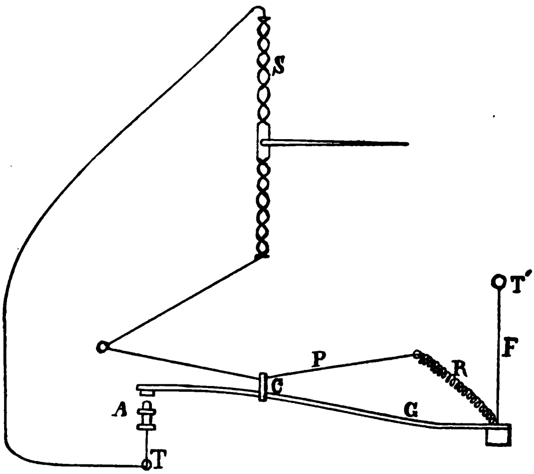


Fig. 39.

kind, capable of indicating from a fraction of a volt to 2½ volts, have been constructed to operate with so small a current that the waste was about one watt. This would show an extremely delicate construction of strip. But the range of the instrument may be increased or adapted to the measurement of higher potentials by inserting resistances into the circuit, but of course this arrangement would require the expenditure of more energy in the instrument.

The arrangement of the circuit and the means adopted for the safety of the instrument, if it should be placed in a circuit carrying a potential higher than the strips could carry with safety, are shown in Fig. 39, where *T T'* represents the binding posts of the instrument. A fusible strip is shown at *F*, and the coil of wire *R* is an adjustable resistance to regulate the flow of current through the strips. The wire *P* forms a portion of the circuit, and is tightly stretched, carrying at its center a loop *C*, of insulating material, which holds the spring *G* suspended and out of contact with the point at *A*. But should too much current be sent through the instrument, it would heat the wire *P*, which would expand and be drawn down by the spring *G* until the end of the spring came in contact with the point at *A*, which would produce a short circuit of low resistance between the binding posts, and allow a flow of current sufficient to melt the fuse *F*, and open the circuit. This would occur before the strip could be injured.

In the manufacture of these instruments a method of treating the strips is adopted by which the set of the strip is made permanent, so that no readjustment is afterwards necessary on account of the use or disuse of the instrument. The method consists of sending a current, much stronger than the strip is intended to carry, through it at intervals. The arrangement by which this is performed, is to cause the second hand of a clock to pass into and out of a bath of mercury during each revolution, closing and opening the circuit. This process is continued for three days and nights, after which it is found that the strip undergoes no change of elasticity. In the case of the low potential voltmeter for the measurement of alternate currents, the 2½ volt instrument may be used through

any range whatever by placing a small transformer on the base of the instrument. If the transformer is reasonably free from self-induction and contains a sufficient quantity of iron, it will make no difference whether the frequency of alternation of current is 50 or 100 per minute, and the instrument may be employed as an ammeter capable of indicating 1.000 amperes or more, or as a voltmeter to the measuring of 1,000 volts and upward.

CHAPTER XVI.

RECORDING METERS.

A very important class of meters are those whose office it is to record the amount of current made use of in doing the work, whether it be the production of light or the development of power. A number of instruments have been brought out for this purpose, most of them being quite accurate over a wide range; but as a single instrument cannot be expected to cover the whole field of usefulness in any one line, the instruments are made of different sizes to meet the requirements of varying service, the smaller ones measuring with practical accuracy the least amount of current required. In the meter shown in Fig. 40, the principle of its operation is that of a motor driving a train of gearing. The action of alternating currents in inducing currents in the closed circuit of a neighboring conductor is utilized in this connection to produce a motor requiring neither commutator or brushes or any connection whatever with the inducing or main current to be measured. The motor consists of a flat ring of soft wrought iron mounted on a light disc of brass, as shown at *A* in Fig. 41. The disc is mounted on a slender steel shaft, which carries near its lower end four vanes of light material which are acted on by the resistance of the air as their speed of revolution increases, while the upper end of the shaft carries a small pinion which engages with the

train of gearing forming a portion of the register. Closely surrounding the disc, but not touching it, are several flat plates of copper, in the form of long links, riveted together at the ends. These are so arranged that their position may be adjusted in respect to the coils of wire *C C* which

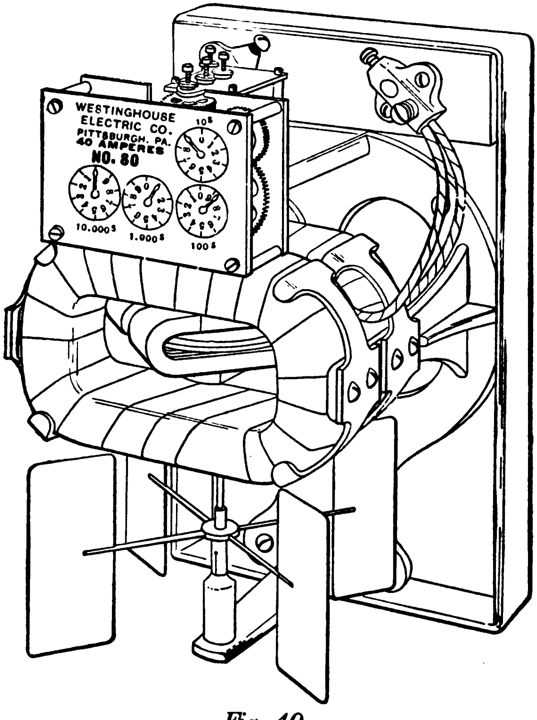


Fig. 40.

surround the whole and carry the current which the instrument is intended to measure. These coils are connected in multiple and form a portion of the lamp circuit.

The principle upon which this appartus operates may be understood from the following considerations: If two

closed conductors are placed near to a coiled conductor through which an alternating current is caused to pass, the induced currents in these two conductors will be approximately in the same direction at very nearly the same instant; but the currents in these conductors will differ in phase from the inducing current. Under these conditions there will be a repulsion between the two secondary circuits, depending on the amount of the primary current and on the displacement of phase between the inducing and induced currents. If one of these secondary conductors be fixed and the other movable, it is evident that if the action can be continued so as to produce the repulsive effect always in the same direction, a continuous rotary motion can be produced by the inductive effects alone and without any direct connection with the inducing current. If, in place of one of these secondary conductors a core of iron is used, the attraction between the inducing coil and the iron core will serve in place of the repulsion between the two secondary coils, and with greater effect so long as proper proportions are had and arrangements made to carry out the same mode of operations. In another way, if a disc of iron be surrounded by a band of copper and outside of this is another closed conductor, at an angle to the inducing coil, the passage of a current through the coil will induce currents in the closed conductor and the disc, which will cause the disc to rotate, and the speed will be almost directly proportional to the square of the current, so long as the rate of alternation is maintained about the same.

The action of the current and the operation of the instrument may be explained as follows: An impulse of current in the inducing coil will induce a current in the

opposite direction in the ring of soft iron forming a portion of the disc and also in the closed conductor, the fields of force produced, being of opposite signs, will attract and cause the disc to revolve. The currents induced in the closed conductor being the same as those in the disc will cause a repulsion between the disc and conductor, and for that reason may be used as a means of calibrating the instrument. If the copper loop be moved into a position bringing it in line with the coil, there will be no action on the disc, because the coils will then have their greatest

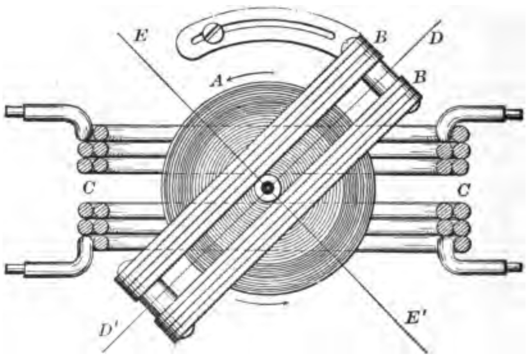


Fig. 41.

mutual induction, and if the loop is placed at an angle of 90 degrees this will bring the loop in a position where no current is induced in it and there will be no action on the disc; but when the loop is set at an angle of 45 degrees to the coil then the attractive and repulsive forces combine to produce the greatest action on the disc. When the loop is adjusted in the position shown in the cut, the rotation of the disc will be in the direction shown by the arrows; but if the loop should be moved to the opposite side in the position shown by the line *E E'* the rotation of

the disc will be in the opposite direction. As the speed of rotation increases as the square of the current, it is necessary to provide some means by which the speed will increase directly as the increase of current. This is provided for by the vanes attached to the lower part of the shaft, for as the speed increases the resistance of the air opposing their movement increases in almost exactly the same ratio, so that the revolution of the disc increases in practically the same proportion as the current. The registering apparatus is similar to that of a gas meter, the several spindles carrying gear wheels and pinions which mesh together, and are proportioned as ten to one so that the reading may be carried as high as desired. The instruments are made to register in lamp-hours or ampere-hours, so the consumer can at any time tell the amount of current used.

The Slattery induction meter, an instrument somewhat similar in principle, is shown complete in Fig. 42, and consists essentially of a light cylindrical armature composed of copper rings separated by iron discs arranged on a light steel shaft placed in a vertical position. The armature is surrounded by a closed circuit formed of metal plates separated by air spaces, and made to inclose the armature in a manner similar to the pole pieces of a dynamo, with the exception that the plates enclose the ends of the armature also, as shown in Fig. 43, and where the copper rings *a a a*, of the armature, are shown separated by the iron discs which project slightly beyond the copper. Enclosing the armature is the closed circuit of plates *b*, *b*, arranged in two divisions, completely enclosing the armature with the exception of a small neutral space through the middle. The coil formed by these plates is arranged

so that it may be moved through an angle of 90 degrees. Encircling these are two flat primary coils of wire forming a portion of the lamp or work circuit through which the current to be measured flows. In principle and action this meter is in some respects similar to the one just described, although differing considerably in other respects. The combination of the two coils, the inner or

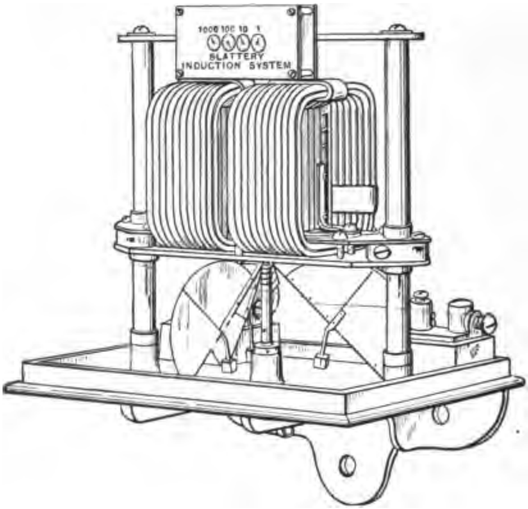


Fig. 42.

closed coil *b*, *b*, being set at an angle to the outer one, carrying the primary alternating current, induces a secondary current in the closed coil which lags about a quarter of a phase behind the first and induces a current in the armature. The fields of force resulting in the coil and armature have their opposing poles separated at an angle, the attraction causing the armature to revolve. This apparatus is virtually an alternate current motor, the

speed of revolution, as well as the direction of rotation, being governed by the angularity which the closed secondary coil bears to that of the primary coil. By increasing or diminishing the angle from 45 degrees the speed is reduced, for it is at this angle that the action of the fields of force in the closed coil and in the armature have their strongest action on each other. By moving the coil *b*, *b*, to a position which will bring it parallel with the primary coil the action on the armature will cease because the induction is then direct and wholly between the primary and secondary coils, there being no inductive effect produced in the armature. A similar effect will result from placing the two coils at an angle of 90 degrees. In this position there will be no inductive effect whatever, and consequently no force acting on the armature. The recording apparatus is of the style generally employed for such purpose in gas, water and other meters, such as described in connection with the recording electric meter shown in Figs. 40 and 41, the armature shaft being connected to the registering apparatus in a similar manner.

In this instrument the device employed to produce the required retarding effect to make its speed proportional to the current, which in this instrument does not follow the law of the square of the current, since the retarding effect becomes more and more disproportionately great as the speed increases. To overcome this and make the speed directly proportional to the current, the air vanes, shown in Fig. 42, are joined in such a manner that as the speed of rotation increases the exposed surface of the vanes is decreased in such proportion as to make the speed of rotation almost absolutely proportional to the current throughout the whole range of the instrument. The manner in

which this result is obtained is shown in the lower part of the instrument, as seen in Fig. 42. It will be noticed that each vane is in the form of a half circle, and consists of two parts joined together near the lower line of the vanes, the outer portion being free to move while the inner portions are firmly attached to the rods projecting from the

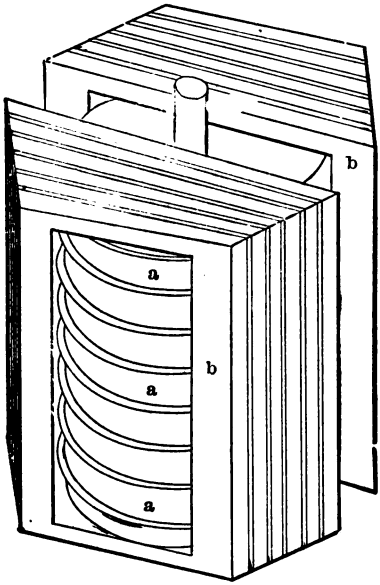


Fig. 43.

armature shaft. To produce the required decrease of surface of the vanes, the outer portion has connected to it the short lever and weight, shown in the cut, the weight as it hangs pendant keeping the full surface of the vane exposed; but as the speed of rotation increases the tangential energy carries the weights outward, which causes the movable portion of the vane to close over the fixed

portion, thereby reducing the area exposed and reducing the retarding effect of the resistance of the air, so that the relative speed bears the required relation to the current. The operation of these meters is quite satisfactory in use, as there is very little about them to get out of order if they are kept free from dust. This is provided for by a glass case which covers the instrument. Adjustment may be made at any time, if required, by changing slightly the position of the closed circuit *b b*, so as to increase or decrease the angle between it and the primary coil as required, but this is seldom necessary, for the wear on the instrument is very slight, and so long as the alternations remain the same the registering will be found practically correct throughout the full range of capacity.

WATT METERS.

The recording meters already described in these articles, are for recording ampere-hours or lamp-hours, and are not adapted to the measurement of the work done on circuits, as they measure only the current passing through the meter. The instrument shown in Fig. 44, although bearing a certain resemblance in general appeance to the others, yet varies considerably from them in the princles on which it operates, and the method of construction. It measures, as its name indicates, the number of watt-hours developed by the energy passing through the circuit to which the instrument is connected. As the watts are the summation of the energy of the current, the product of the number of volts by the number of amperes, the register indicates the full amount of power used, and for this reason the meter may be used for the measurement of the amount of power consumed on any circuit, whether it be

applied to lamps, motors or other purposes. The principles utilized in its construction are such as to make it adapted to the measurement of either continuous or alternating currents without change of any kind, and its registration will be accurate throughout the entire range of its capacity. The readings are given direct in watt-hours, so that no mathematical calculations are necessary to deter-

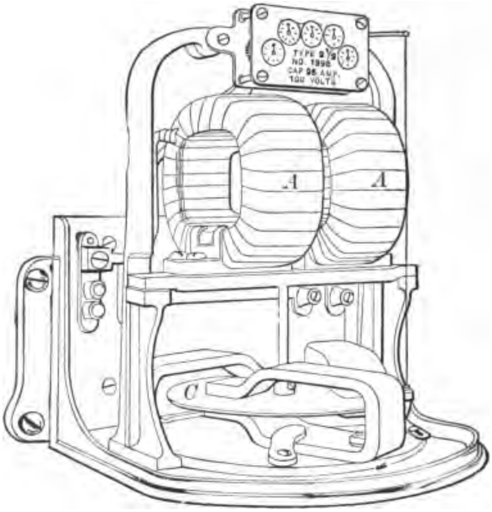


Fig. 44.

mine the amount of energy delivered during a given time. The design of the instrument is of such simplicity as to be easily understood, and the lack of complication reduces the liability of its getting out of order, so that by proper care in excluding the dust, the instrument will require practically no attention and no repairs.

The construction of the instrument is clearly shown in the cut, where the flat coils of insulated wire marked *A A*

form the field, and inside of which the armature is placed. The fields form a part of the circuit through which the current to be measured passes. The armature is of the ordinary Siemens type wound in sections, the terminals of which are connected in closed circuit to a commutator on the shaft, in the same manner as is usually the practice with continuous current machines. Two brushes bearing on the commutator provide for the passage of the current. The armature is wound with fine wire which offers considerable resistance to the passage of the current, so that but a small portion of current will pass through the armature. This is necessary as the armature circuit is connected in shunt with the work, so that when connected to multiple circuits the armature circuit receives the full potential of the current in the mains. By such arrangement the record of the instrument is produced fully as much by the pressure of the current as by the number of amperes passing, and is in fact the product of the two, or the number of watts per hour. The action of the current in producing this result may be better understood by considering that the field is produced by the amperes of the current, while the current through the armature is the result of the potential on the mains acting through the resistance of the armature circuit, and also that this is varied by the speed of revolution, for, as the armature and field together constitute a motor, the effect produced by the armature revolving in the field is to produce a counter electromotive force in the armature circuit. The effect of this is the same as so much added resistance, and the amount of current that will pass through the armature is reduced in the same proportion; but an increase of armature speed is produced by an increase in the strength of

field produced by an increased flow of current in the work circuit, the potential remaining the same. In this motor, as in all others, the speed of revolution increases as the square of the current, so that it becomes necessary to introduce some device to produce retardation in a manner that will make the speed proportional to the work done. This is secured by the use of an inefficient dynamo, which produces the retarding effect in the desired proportion. This is attached to, and driven by, the motor shaft. This device bears some resemblance to Faraday's disc, or the wheels of Barlow or Sturgeon, and consists of a brass disc placed horizontally and forming the lower portion of the apparatus. The disc revolves between the poles of three separate horseshoe magnets placed at approximately equal distances apart. The cut shows these quite clearly. The disc of Faraday, is a metal disc movable in a magnetic field on an axis parallel to the direction of field. Such a disc, if caused to revolve, will generate a difference of potential that may be caused to produce a current if a circuit is provided having one of its terminals near the center and the other at the circumference of the disc, the body of the disc forming a part of the complete circuit. This device will act as dynamo or motor, depending on whether the disc be caused to revolve by power being applied or current being supplied to the circuit. Employed in either manner its efficiency is not sufficiently great to make it of much utility, except for some such purpose as its present use in the recording instrument described. By providing a number of magnetic fields through which the disc is revolved, the retardation can be made to bear any required proportion to the increase in the speed of rotation, for currents are produced in the disc by each of the fields through

which it revolves. The recording appartus used in the instrument is of the style commonly found in the various recording instruments, and consists of a train of gearing receiving its motion from a worm on the upper end of the armature shaft, which meshes into the gearing. The applicability of this instrument to the measurement of power used on any circuit is clearly shown by the principles used in its construction, which adapt it for use on either constant potential or constant current circuits. As the same principle of connecting into circuit will give the same accuracy in the register, that is, connect the field coils to the circuit in series, and the terminals of the armature circuit in shunt to the work, the reading in watt-hours will possess the same accuracy whether the potential or the current is the variable quantity, for, if the current through the work circuit and field coils is constant the loss of potential will cause a certain portion of current to be shunted through the armature, and the record will show in watt-hours the power absorbed on the circuit.

The meter shown in the accompanying cut, Fig. 45, possess some features which differs considerably from any possessed by the instruments already described. The disc or armature in this case consists of copper alone instead of copper and iron as in the others; but where the others have no iron in the field, relying on the field of force produced in air, this instrument utilizes iron magnets and pole pieces, thus increasing the intensity of the magnetic circuit, as iron is a much better conductor of the magnetic lines of force than air. To adopt the magnets to use with alternate currents they are laminated, being made from sections of thin sheet iron. There are two of these magnets of the shape shown in the cut, and placed so as to

enclose the rim of the disc at an angle of 90 degrees apart, as shown in the plan view given in Fig. 46. One of the magnets is wound with coarse wire and forms a portion of the work circuit, the other being wound with fine wire and connected in shunt with the work between the mains. In the meter shown in Fig. 44, the armature circuit is connected between the mains in a similar manner, and the current which passes is limited by the resistance of the

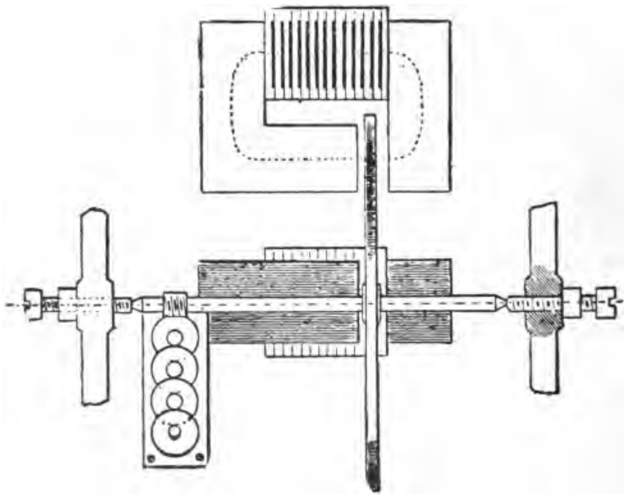


Fig. 45.

armature circuit and the counter e. m. f. developed, which acts as an additional resistance, reducing the flow of current through the armature circuit as the speed of revolution is increased. The increase of back e. m. f. would be proportional to the speed if the magnetism of the fields remained the same, but as this changes with the amount of work being done on the circuit, increasing the counter

e. m. f. as the work is increased, so that some retarding influence is necessary in order that the speed may be proportional to the current. In the meter shown in Figs. 45 and 46, the necessary retarding effect is produced by the influence of the field of force produced by the second or fine wire magnet. The rotation of the copper disc is produced by the action of two fields of force inducing cur-

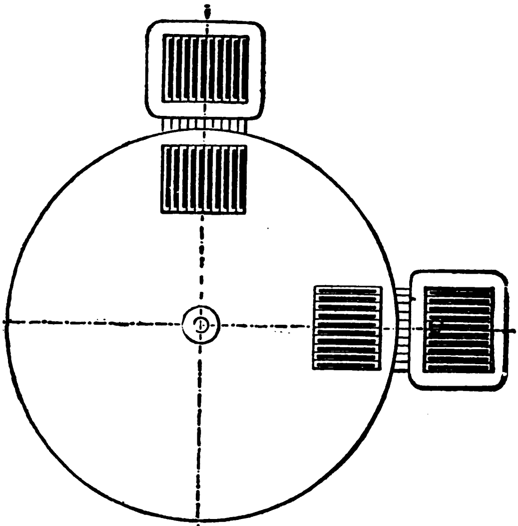


Fig. 46.

rents within the metal of the disc of such a nature that there is a strong repulsion between that portion of the disc located between the magnets and the magnets themselves. The action of one magnet being in opposition to that of the other, causes the resulting action to produce in the disc a speed of revolution which is somewhat greater than would be proportional to the current flowing in the work

circuit; but when the armature or disc is in motion induced currents are set up in the metal by its movement through the magnetic fields, which act in proportion to and retard its rotation to such an extent as to make the speed of rotation directly proportional to the current flowing in the circuit. The counting mechanism, which is of the usual type, shows by the pointers on the dials the number of ampere-hours which have been transmitted. The current required to operate this instrument is very small, not exceeding one-fourth of an ampere. This sensitiveness is produced in part by the reduction of the friction to the lowest limits, and the use of the iron in the magnets. The simplicity of the instrument is such that there is little to get out of order or become disarranged, and the proportioning of the parts insures that the record will be correct without the necessity of frequent adjustment.

CHAPTER XVII.

GENERATORS IN PARALLEL.

There are some peculiarities about alternate current generators that enable two or more of them to be worked together in parallel under certain conditions when the machines are separately excited. Many of the alternate current dynamos can be used as a motor when supplied with current, and the motor will be perfectly self-regulating as regards speed in spite of load variation, provided it is not overloaded, as it will keep perfect time with the generator. But a motor of this kind cannot start itself as continuous current motors do, but has to be independently driven up to the same speed as the generator from which it receives the current; after which it will keep in motion at the same speed, and the load on the motor may be varied to any extent within its limit without varying the speed of the motor. Even when slightly overloaded the motor will show a strong tendency to keep in beat with the generator, but when the synchronism is once broken the motor rapidly slows down until it stops. To set it running it must be independently started and driven up to the speed again before being thrown into circuit. These motor properties of an alternator dynamo make it possible to work two independently driven alternating generators in parallel on the same circuit, that is, so that the armature of both machines supply current to the same

circuit. But in order that the machines shall come into step, that is, that the alternations shall correspond at the same instant, both machines must separately be brought up to speed and generate current and be held there until their phases correspond before their circuits are coupled together. In order to determine the instant when the machines are to be thrown together it is necessary to make use of some device that will clearly indicate the pulsations or phases of the current. The rise and fall of the positive impulse and the same phases of the negative impulse have to be considered, and unless these coincide in both machines at the instant they are thrown together the currents from each will interfere, and by acting in opposition would tend to reverse the weaker machine. Two machines to be worked in parallel must necessarily give the same number of alternations per second, and, further, they must correspond in phase at all times. A phase indicator for this purpose, and in use to some extent, is shown in the diagram Fig. 47, where two primary circuits are represented by C, C_2, the transformers being connected to this circuit as shown by t, t_2, etc. Means are provided for connecting these circuits together by the plugs P, P_2, so that they may be operated as a single circuit. The dynamos are shown at A, A_2, the latter being connected to and working on the circuit. Double pole switches are provided between the dynamos and circuits, the one on the circuit to A, being open when the machine is not in circuit. When the load on the mains become too great to be safely carried by one dynamo the other machine is started and set to work on a bank of lamps or other resistance located in the station. There are in circuit with the dynamo a bank of lamps as shown at L, these being connected with the

transformer which is represented by the zigzag line. The reason for putting the machine at work before cutting it into circuit with the one already in operation is to allow it to become fully excited and to be at work so that the phases of the machine may be indicated. In this respect alternate machines differ from the continuous current dynamos, for the latter may be coupled in multiple or series at any time when up to speed, providing the necessary connections are made to the circuits. But it is necessary for the alternators to be doing about the same amount of work and generating the same e. m. f., and that their phases coincide when thrown together, in order that there will be no change in the brilliancy of the lamps at the time that the current of the second machine is added to the circuit. To determine when the phases coincide, a branch is taken from the poles of each generator and led to a pair of transformers T, T_2, placed near each other and having their secondaries connected in series through a couple of incandescent lamps represented at l, l_2. The circuit of the phase indicator is provided with a double pole switch, and when the circuit is closed through this, both alternators being in operation, the transformers T, T_2, work together on the two lamps, and according as the phase of the two machines are together or opposed, the lamps will be glowing or darkened, and the moment that both lamps are out the two machines are in step, although on different circuits, and should then be thrown together by closing the double pole switch S_2. So long as the machines are out of step the lamps l, l_2, will pulsate in brightness, producing luminous beats in consonance with the pulsations of current, as the impulses are more nearly opposite. The reason for taking the instant when neither lamp shows

any light as the indication that the machines exactly correspond in phase is that the currents in the transformers T, T_2 are opposed to each other and the electromotive force from each neutralizes that from the other, and no current will then flow through the circuit of the phase indicator. By a little study of the diagram, and considering what was said about the action of an alternator while being run as a motor, it will be understood that there is more or less limit to the coincidence of the phases of the

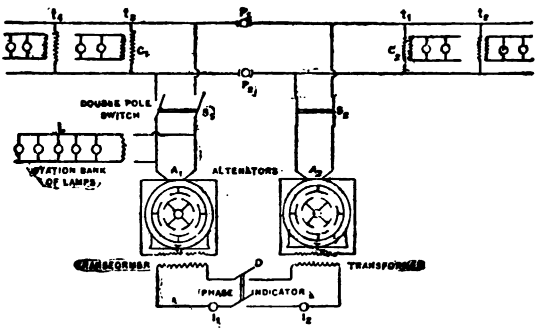


Fig. 47.

two machines at the instant when they can be thrown together, for the action of one on the other is sufficiently strong to bring the phases into synchronism if the rate of alternations are approximately the same in each and the phase dose not differ too greatly at the instant when they are thrown together. The phase indicator is not sensitive enough to show the instant when the e. m. f. of the two machines is in exact opposition, for a given amount of current is required to produce a visible color in the filaments of the lamps, and the two lamps being in series,

double the amount of electromotive force is required to that which would be sufficient to produce the necessary current to cause one lamp to glow visibly. So it will be seen that there may be considerable difference in the phase of the machines and still neither of the lamps will show any indications, because there is not quite enough e. m. f. developed in one direction at the time to cause the lamps to glow. While the phases are so nearly coincident as to give this result they are near enough to allow the machines to come into step easily and continue so as long as speed is kept approximately equal. After the dynamos are thrown together the bank of lamps on which the second machine has been working is gradually reduced in number, the regulating properties of the dynamos and transformers permitting the reductions to be made, until the whole bank of lamps are cut out. This arrangement has been successfully used in some stations, and may be all that is required, but most stations prefer to run several separate loops from the station, and when the total load is more than can be handled by a single dynamo the circuits are all connected together and operated by a single machine. This is the common practice. As the load increases by the turning on of additional lamps the circuit is divided, a portion of the load being thrown on to another machine. Where the circuits contain a large number of lamps the circuits may be divided several times, an additional dynamo being brought up into use to operate each section. This plan has been found to be the most convenient and reliable, as it does not require that the dynamos be run at the same speed, and the accidental slipping of a belt, or irregularity in the action of a governor, produces but a momentary fluctuation of the lights, when, if the dynamos

were working in multiple, any of the accidental occurrences would throw the dynamos out of step and cause the fluctuation and total extinguishment of the lamps until the machines were again brought into step.

CHAPTER XVIII.

OHM'S LAW.

Ohm's law of electric currents is simplicity itself and as comprehensive as it is simple, and no man can expect to have more than a slight knowledge of the action of electric currents who does not clearly understand the laws by which they are governed. Without going into a history of electricity previous to the time that Ohm discovered the law of currents, it is only necessary to give it as he expressed it, together with some of its applications, to show its extreme simplicity and how it may easily be remembered and applied by engineers to a better understanding of the working of the apparatus of which they have charge.

As usually given the law reads: *The strength of the current in any circuit is directly proportional to the difference of potential or electro-motive force in that circuit, and inversely proportional to the resistance*, or in other words, the elctromotive force in volts, divided by the resistance in ohms, will give the current in amperes flowing in the circuit. This is quite simple and may be easily understood by any one having a knowledge of simple arithmetic. Apply the law as given to determining the amount of current in amperes required by an incandescent lamp having a resistance when hot, of, say 200 ohms, and working on a 115 volt circuit. Then e. m. f., 115 volts, divided by the resist-

ance, 200 ohms gives .575 ampers as the amount of current that would pass through the lamps.

The law as given above is expressed in formula by $C=\frac{E}{R}$ where C represents the current in amperes, E the e. m. f. in volts, and R the resistance in ohms. From this form two others are derived by which the e. m. f. or resistance may be easily calculated when the value of the other factors are known, as follows:

$$E=C\times R$$

$$R=\frac{E}{C}$$

To illustrate the use of these formulas, several examples may be worked out in the following manner: How many amperes of current under a potential of 110 volts will pass through a resistance of 20 ohms?—$110\div 20=5.5$ the number of amperes, and in all cases the e. m. f. or potential, in volts, divided by the resistance in ohms, will give the current in amperes. In the next formula the e. m. f. or potential is to be determined. Take a simple proposition, which is as good as any. If it is proposed to send a current of 25 amperes through a resistance of 10 ohms, how much e. m. f. will be required? According to the second formula e. m. f. equals current in amperes $\times$ resistance in ohms, so $25\times 10=250$, the number of volts pressure or difference of potential that will be required.

To calculate the resistance when the e. m. f. and the amperes of current are given the third formula is used. Suppose it is desired to take 5 amperes of current from a circuit giving a constant potential of 110 volts, how much resistance must be interposed? The formula shows that

the e. m. f. divided by the current equals the resistance, so from the figures given $110 \div 5 = 22$ ohms as the resistance which will be required.

These fomulas are so simple and so easily worked that any person who has anything to do with electric light plants should not fail to make themselves familiar with them, and be able to apply them to any question that may come up regarding e. m. f., resistance or flow of current, for they will be found to apply in all cases.

POWER AND HEATING EFFECT OF CURRENTS.

The heating effect of the electric current is a subject of fully as great, if not more, importance than any other connected with the distribution of electricity, and its importance makes it worth the time and trouble required to understand it by any one who has anything to do with electric conductors.

The value of electricity as a means of producing light is directly due to the heating effect. In the electric welding apparatus the heating effect is plainly visible, and it is manifested to a somewhat less extent, though fully as evident if not visible, in the various forms of domestic apparatus produced with the view of utilizing this one effect. The list of useful devices utilizing this effect of the current, making it applicable to practical purposes, is already too long for enumeration in this connection, for it covers a great variety of cooking utensils, apparatus for heating rooms or water, warming beds, and little devices are constructed to serve the same purpose as the hot brick or water bottle that is sometimes placed at the feet of invalids. Useful apparatus for laundry use have also been introduced and economically as well as quite satisfactorily

operated. Sad-irons that can be attached by a flexible conductor to a lamp socket, and the iron heated ready for work in one and one-quarter minutes, retaining the same heat thereafter so long as the current passes through them, are in use in many places. But the applications of heat generated by the electric current are already too numerous to admit of even a short description of them being given. While this quality of the current may be applied in many useful ways, it frequently happens that considerable loss is incurred by the heat being produced under conditions which make it imposible or undesirable to utilize it.

As electric lighting is one of the most important branches of electrical engineering, and one which is wholly due to the heating effects of the current, it becomes necessary, in calculating the effects to be produced, that the value of each of the factors be known and considered. As in steam engineering there are certain units in use, by the relative value of which, when known, we are able to calculate the full amount of work to be done as well as the losses incurred, a similar set of units has been prepared for use in electrical calculations, having different names and values from those we, as engineers, are familiar with. The electrical units each have a mechanical value which makes the two sets of units practically interchangeable. The heat generated in an electric circuit is found to increase as the square of the current, as with twice the amount of current there would be four timès the quantity of heat generated; with three times the current, nine times the amount of heat. As the quantity of current is the result of the electro motive force or pressure divided by the resistance, as shown by Ohm's law, it will be seen that the pressure may be left out of the calculation if we make use

of the rule: The heat generated in a circuit = the square of the current multiplied by the resistance. This is more conveniently expressed by the formula: $W = C^2R$, where W is the unit of heat or work, C the current in amperes, and R the resistance in ohms.

The watt is the unit of power, P, and

$$
\begin{aligned}
P &= E \times C. \\
&= C^2 \times R. \\
&= E^2 \div R. \\
&= 1\text{-}746 \text{ h. p.}
\end{aligned}
$$

where E is the electromotive force or pressure in volts and the other letters have the same meaning as given above. The unit of heat or work W is called the joule, and is one watt per second, and may be found from the following formulas:

$$
\begin{aligned}
W &= E \times C \times t. \\
&= C^2 \times R \times t. \\
&= E^2 \div R \times t. \\
&= .7373 \text{ ft. lbs. per second.} \\
&= 44.038 \text{ `` `` `` minute.} \\
&= .0573 \text{ heat units ``}
\end{aligned}
$$

Electrical energy, heat energy, and mechanical energy may be converted any one into either of the others, so that by the use of the above formulas any problem relating to the power, heat, or work of the electric current may be worked out. Take an example: What power will be required to operate ten 16 c. p. incandescent lamps, each requiring 100 volts and .7 amperes?—As the unit of power is the watt, and as volts × amperes = watts, then in the present case we have $100 \times .7 \times 10 = 700$ watts. An electrical h. p. is equal to 746 watts, so $700 \div 746 = .938$ h. p.

How many watts per c. p. do these lamps require?—

The number of watts required by each lamp as found in the previous example is 70 watts. As each lamp is 16 c. p., the power required will be $70 \div 16 = 4.375$ watts per candle power.

What amount of heat will be developed in each lamp per minute?—The unit of heat is the joule, and equals one watt per second. As each lamp requires 70 watts, and there are 60 seconds in a minute, then $70 \times 60 = 4{,}200$ joules, and as a joule = .0009551 heat units per second, then $4{,}200 \times .0009551 \times 60 = 4$ heat units per minute. As one h. p. is equal to 42.75 heat units, it will be seen that the calculation agrees with the previous one. How much power will be lost in a circuit having a resistance of 18 ohms and carrying a current of 10 amperes? According to the formula $W = C^2R$, we find that in this case $C = 10$, so $C^2 = 100$ and $R = 18$; then $100 \times 18 = 1{,}800$ W or joules. As the joule = .7373 ft. lbs. then $1{,}800 \times .7373 = 1{,}327.14$ foot pounds per second, or $1{,}800 \times .0009551 = 1.71918$ heat units per second, or as $\frac{C^2R}{746}$ = electric horse-power, we have $1{,}800 \div 746 = 2.4$ h. p. wasted.

The heating effect of the current on conductors is subject to numerous conditions, so much so that it is a very difficult matter to formulate a rule from theoretical considerations alone that will apply practically. By the rule of C^2R we can easily determine the loss in the conductors, but as the temperature rises radiation takes place, and heat does not accumulate to the same extent as though radiation was hindered. The specific heat capacity of the metal must be considered also, as each metal has a different capacity for heat; that is, one metal will absorb a greater quantity of heat than another before its temper-

ature will be raised a given number of degrees. Taking a specified weight of water for instance, where 1,000 units of heat would be required to raise the temperature a certain number of degrees, the same weight of iron would have its temperature raised the same number of degrees by the absorption of only 125 units of heat, while the same weight of copper or zinc would be similarly effected by only 95 heat units. But of the common metals which have a very low specific heat capacity, silver requires 57, platinum 34, mercury 33, and lead but 31, bismuth being lower yet, as under the same conditions it would require but 23 heat units to raise the temperature the same number of degrees. If the same number of heat units are generated in a conductor whose radiating surface is small, the resulting temperature will be much higher than if generated in a wire having a much greater radiating surface. It has been found that the temperature which a wire will acquire by the passage of a current through it varies with the third power or cube of the radius. As the heat generated increases as the square of the current, the resistance remaining the same, the temperature would increase in the same ratio if no heat was radiated, but as the resistance increases with the temperature and the radiation is proportional to the surface, it is found that the increase of temperature will depend on the heat developed per second minus the amout radiated per second. The amount radiated will also depend on the temperature of the wire and the temperature of the surrounding medium; for the greater the difference of temperature between the two, the more heat will radiate in a given time.

Numerous tables have been made showing the temper-

ature attained by conductors carrying currents at given densities under the usual conditions of use of electric light wires, while other tables have been arranged to show the greatest amount of current that can be safely carried by conductors of a given size. The practice in electric construction work is to refer to the tables for information, as requiring less time and giving as great a degree of accuracy as would be obtained by applying the formula to each separate case. Numerous illustrations might be given showing the application of the formulas to the various purposes to which the electric current is applied, but sufficient has been given to show the application of heat and power formulas.

CHAPTER XIX.

GROUND ALARMS AND LEAK DETECTORS.

Among the automatic devices designed for indicating the presence of a leak, or ground on an electric light circuit, there is one which acts with never-failing certainty and promptness, and will give the indications as soon as the insulation resistance has fallen slightly, or a dead ground is formed. This device is the invention of Mr. C. H. Rudd, who is now connected with the Western Electric Light Company, of Chicago. It is applicable to any kind of electric circuit, and by the use of supplementary apparatus the insulation resistance of the circuit can be readily measured, while on series circuits the location of the leak or ground can be approximately determined. This ground detector and alarm consists of the arrangements and devices shown in Fig. 48, where the dynamo is represented at *D*, and the marks, ×, represent arc lamps on the lighting circuit. The circuit containing the ground-detecting devices, it will be noticed, is placed in shunt with the dynamo, each side of the loop connecting to one side of the condensers represented at *C C*, the other side of the condensers being connected to ground by a wire which is common to both. Connected into this portion of the circuit is a telephone drop *A*. The small local circuit marked *L*, consists of a battery and vibrating bell which rings an alarm as soon as a leak is formed which will produce a static charge in the condensers.

Condensers are usually formed from square sheets of tinfoil, made into a pile, the sheet being separated by sheets of insulation somewhat larger than the foil. The insulation generally used for this purpose consists of mica, silk, or sheets of paper saturated with paraffine. In building them up a few sheets of the insulation is first laid down, and on these a piece of the foil is laid, then another

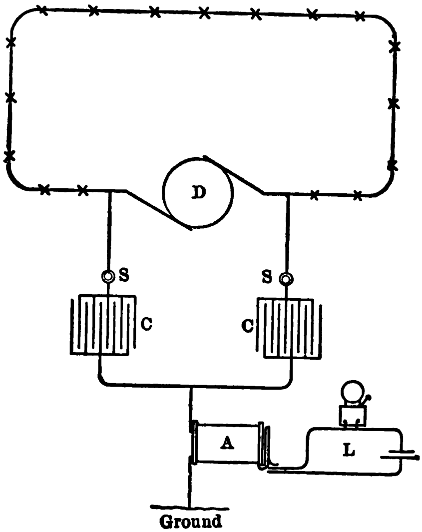


Fig. 48.

sheet of insulation is placed on this, followed by another piece of foil, and so on, until the amount of foil used is sufficient to provide the amount of surface required to condense the electricity under sufficient potential to act on the drop. The sheets of foil used have a strip projecting on one side, and as the foil is placed in the condenser, the strip from the first sheet is left projecting at one side, and

the strip from the next sheet of foil projecting from the opposite side, and so on, alternate strips projecting from opposite sides. These strips are for the purpose of making connections to the condensers, and the manner in which the sheets of foils are arranged is sufficiently well illustrated in the diagram to clearly convey the idea. Each alternate sheet of foil is electrically insulated from those forming the opposite poles, so that under conditions where the insulation of the circuit is so high as to prevent the leakage of any appreciable amount of current, there will be no flow of current through the circuit connecting the condensers to ground. Should a leak occur, however, on any portion of the circuit on the opposite side of the condensers from the ground, the leakage of current would cause a charge to accumulate in the condensers until the potential became so high that a discharge to ground would occur, and in its passage, although the current would be so small as to be barely appreciable, it would still be sufficient to act on the drop and cause the shutter to fall. This telephone drop, as it is called, is simply an electromagnet having a "long coil," or a great length of fine wire, forming many turns around the core. The armature of this magnet holds the shutter or drop in position so long as no current is passed through the circuit, but when the armature is attracted, the shutter is released, and as it falls it completes the local circuit by forcing the two terminals together. This calls attention to the fact that there is a leak in the circuit, and the fallen shutter shows on which circuit the leak has occurred. It is then necessary to find the extent of the leak or drop in the insulation resistance, to determine whether it is a source of immediate danger or not. This is done by the use of the two

pieces of apparatus shown in Figs. 49 and 50; the first of these, Fig. 49, consists of a series of resistance coils, *r r*, connected together by the brass connections *s s s*, which are drilled to form a socket to admit a pin, forming a plug and socket connection. Two flexible insulated conductors, provided at their ends with plugs for making socket connections, are used for connecting this series of resistances to the shunt around the dynamo. One end of each of these flexible conductors is placed in the sockets at the end of the series of resistances, the other end of the conductor being inserted into the sockets *s s* in the shunt

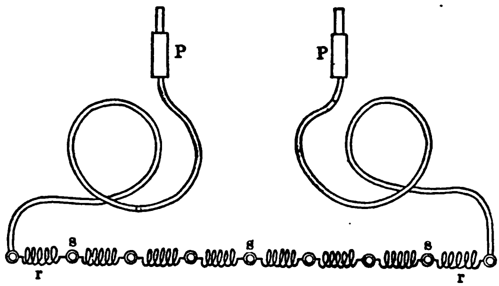


Fig. 49.

around the dynamo, Fig. 48, thus completing a shunt circuit of high resistance between the brushes of the dynamo. In the diagram, Fig. 49, there are but a few of these coils shown, but in the apparatus used in arc lighting, or other high tension circuits, these coils will be one hundred in number, and have a resistance of 2,000 ohms each, making a total resistance on the shunt circuit, between the brushes, of 200,000 ohms, sufficient to protect the dynamo from any possible injury, and at the same time reducing the quantity or current flowing through this circuit to such a small amount that it will not in the least

injure the galvanometer used during the tests and while obtaining the measurement of resistance. The next move is then to find the position at which the resistances on each side of the leak balance. The apparatus shown in Fig. 50, consists of a device which is practically a Wheatstone bridge, or balance, containing galvanometer G, and the adjustable resistance R, and a small battery B, of about four cells. The galvanometer circuit and the battery cir-

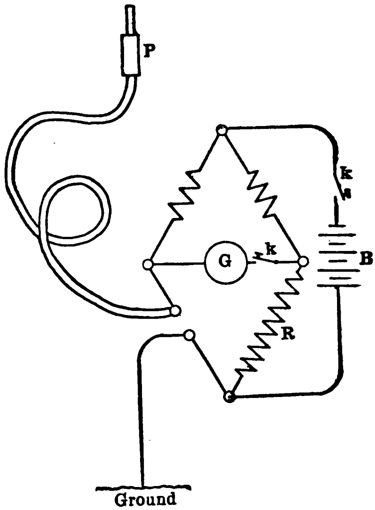


Fig. 50.

cuit both include keys k k, for closing the circuits, which are usualy left open. That branch of the bridge at which the unknown resistance is connected for measuring, is left open, the terminals being fitted with binding posts, or other means for making the connections. In this case one of these terminals is connected to ground, the other being provided with a flexible conductor for connecting to the supplementary resistance. The bridge apparatus is used

as follows: When a leak on the line has been indicated by the drop of the shutter and the ringing of the bell, and supplementary resistance has been connected, the plug *P*, on the end of the flexible conductor connected with the bridge, is inserted in one of the sockets near the center of the series of resistance coils. The key in the galvanometer circuit is pressed down for an instant, the flow of current through the bridge, on account of the leak, causes a deflection of the galvanometer needle, and shows in which direction the current is flowing; whether from the leak to the brúshes, or in the opposite direction, and indicates on which side there is the greatest resistance. The plug in the supplementary resistance is then moved about until the position is found at which the resistances are equal and the dynamo current is balanced, so that there is no appreciable current passing through the galvanometer. When this balance is obtained, the location of the leak on the circuit can be ascertained very closely by comparing the number of spools on each side of the plug, as, for example: If the plug is in the tenth socket on the positive side of the circuit when the balance is obtained, and the lamp circuit contains twenty lamps placed at approximately equal intervals, then the leak would be somewhere near the second lamp on the negative side from the dynamo, because this position would bring the resistances on each side just about equal. After the balance from the dynamo current is obtained, the insulation resistance is then measured by the bridge, using the battery current for this purpose. As it is not always possible to perfectly balance the dynamo current through the resistance coils, it is always customary, in order to get at the correct resistance of the leak, to reverse the direction of the battery current,

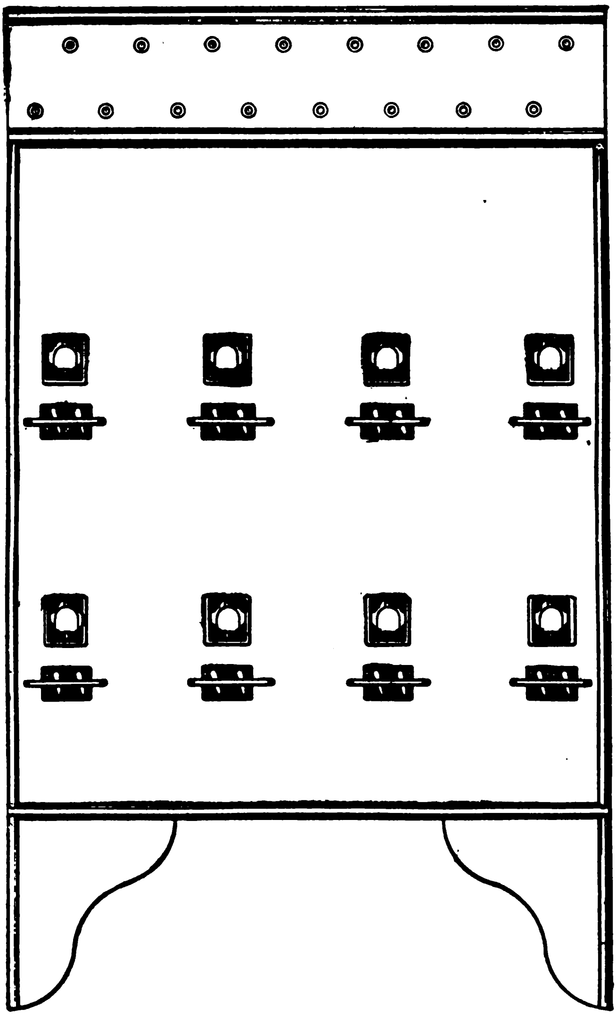


Fig. 51.

which is done by the use of a pole-changer, after the first measurement has been made, and make a second measurement, which will differ more or less from the first, then by averaging the two measurements the correct resistance is obtained. The detector and alarm, or that portion of the device shown in Fig. 48, are arranged on a panel in the manner shown in Fig. 51, where provision is made for eight separate circuits, the sockets shown at the top correspond to the sockets shown at *s s* in Fig. 49, the condensers and other parts of this portion of the device, with the exception of the drops being located on the back of the board. The drops are shown on the face of the panel. There are one or two things that will cause the shutters to drop when there is no leak, but these are well understood by those in charge of the apparatus, so that no difficulty is experienced from such causes, as a measurement of the insulation shows, when made immediately, that there is no trouble on the line. It is usually the case when the dynamo is first started that the shutters will fall, but this is, of course, of no consequence. The flashing of a dynamo will also cause the shutters to fall, but produces no further trouble.

UNIVERSITY OF MICHIGAN
3 9015 00983 9682

DO NOT REMOVE
OR
M ARD